THE INDISPENSABLE FIREMAN.

Standard

Mechanical Examinations

Locomotive Firing and Running

Being the Progressive Examinations for the First, Second, and Third Years, which were Adopted as Standard by the Traveling Engineers' Association. With Answers by W. G. Wallace. Together with Much Valuable Information for Locomotive Enginemen

ILLUSTRATED

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PREFACE TO THE SECOND EDITION.

There is much for the ambitious progressive fireman to learn. The modern locomotive is a wonderful piece of machinery. There are many devices and innumberable parts which make up the complicated mechanism. Much more must be learned and thoroughly understood than the mere operation of the engine and getting the locomotive and train over the road.

The educational requirements demanded of firemen who aspire to be engineers are becoming more and more exacting and much more is comprised in the examinations to which they are subjected than was formerly the case. Every time coal is thrown into the fire-box and every time water is injected into the boiler, certain physical and chemical changes take place. These are facts the fireman now-a-days has to be perfectly familiar with, besides knowing many other fundamental principles which underlie locomotive operation and management.

In order to keep pace with these and other advances it became necessary to greatly improve and add considerably to the examinations so that the Traveling Engineer's Association Questions and Answers as given in full in the irst edition of this book are inadequate for present day nethods.

In this revised and greatly enlarged edition has been ncluded everything necessary to add to the examinations n order to meet the changed order of things and the reatly improved motive power.

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PART ONE

LOCOMOTIVE DETAILS AND CATECHISMS.
EVOLUTION OF THE LOCOMOTIVE.

HISTORICAL SKETCH.

With railroad trains being drawn overland so rapidly that it is possible for the passenger to eat his luncheon in Chicago on the one day and to break his fast in New York the next, it might appear to the lay mind that the limit of speed in transportation has been reached. In view of the developments within a time compassed by the memory of living men, no student of transportation problems dares, however, to attempt to set the final bounds of speed.

Neither will anyone attempt to set limitations upon the ways, methods and means of transportation. The past and present are too full of wonders to allow for a moment the prophesying of a day which will mark the end of these and greater marvels.

The governments of the earth are seeking to make highways for man through the element which hitherto has furnished thoroughfares only for the birds. Roadways on the ocean's bed may yet be traversed. Even now man is seeking to so conquer and control electricity that it may be said before long that steam has had its day.

These things in the mind, little wonder is it that the study of transportation perhaps more than anything else is occupying the attention of man. Articles by the score, and books not a few, have been written upon the broad

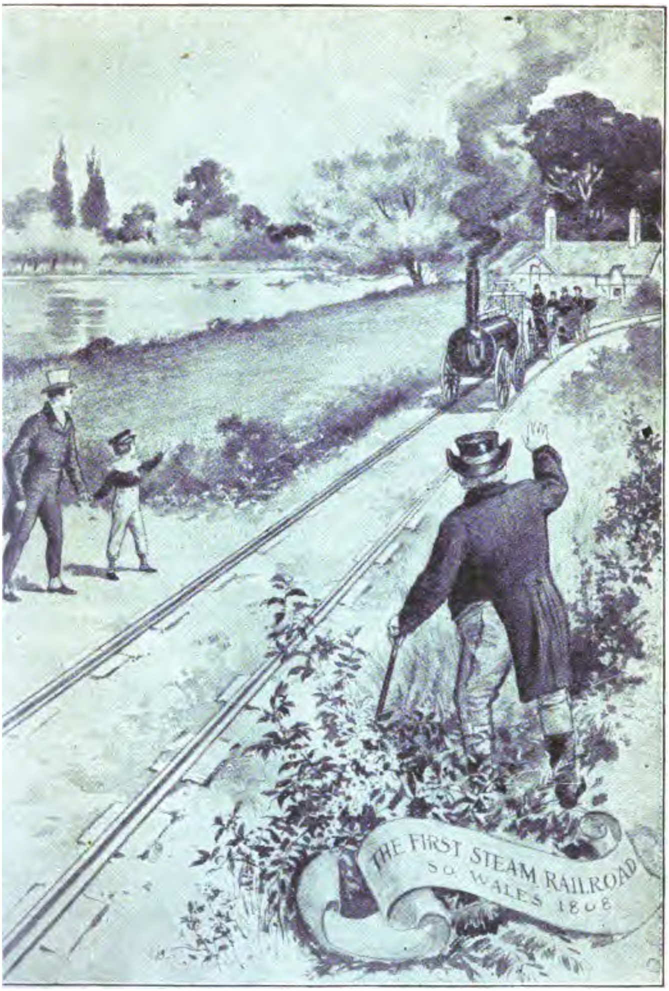

Figure 1. Richard Trevithick Inaugurates the First Movement by Steam upon Rails in the World, at Merthyr Tydvil, South Wales.

From "Railroads Old and New," Verona Tool Works.

subject of the development of transportation, which, put in a homely way, is simply the bearing of burdens from one place unto another. It is a somewhat curious thing that it has been made possible in many places for interested persons to see with little more than a glance that which it would otherwise take weeks of library research to impress upon the mind.

* * * * *

In the Field Columbian Museum in Chicago the progress of the science of transportation is shown in a series of object lessons. It is possible for a man to enter the department of the museum set aside for the purpose and there in an hour's time learn by means of the best teacher —the eye—the development of railway and water way transportation from the day when the first nomad moved his tent until this day, when time and space are approaching annihilation in the ages of steam and electricity.

It perhaps truthfully may be said that this exhibit of the Field Columbian Museum is unique. Of its interest there can be no doubt. It is the purpose here to speak only of that part of the exhibit which pertains to steam propulsion. The institution's officials call the exhibit "The Museum of the World's Rail Way." The word "way" bears a capital letter and has a special significance.

The exhibit was installed immediately after the close of the World's Columbian Exposition by Major J. G. Pangborn, and has been arranged with a strict regard for the lines of transportation development. The student visitor passes through aisles and sees either the originals or perfect working models of practically all the engines and locomotives which marked the beginnings and the advances step by step in the science of steam propulsion.

The surroundings of the exhibit are in keeping with

its nature. In the rotunda of the pavilion is shown the emblematic figure of the railway, a woman riding on a pilot with a perfect model of a locomotive in her arms. The walls are covered with drawings and photographs supplementing the showing of the great iron and steel giants.

The first idea of propulsion on land by steam is made known by a replica of Newton's engine of the year 1680. The engine was reproduced from description. It looks in part not unlike a gigantic tea kettle. In its day it was thought by those to whom steam was but a name, that this child of the good Sir Isaac was of close kin to the devil.

* * * * *

The Cugnot engine of 1769 was the first self-moving steam land carriage of which there is history. Cugnot, by whom it was designed and constructed, was a French army officer. The engine in the Field Museum standing next that of Newton is a full-sized working reproduction of the Frenchman's invention. Cugnot was the first man in the world to apply the high pressure or noncondensing engine with cylinders and pistons to the production of rotary power. The inventor's mind was of military bent and he used his knowledge of steam and mechanics in the making of this engine for the purpose of moving artillery. Like the Newton engine, the boiler part resembles an overgrown tea kettle with three wheels and a wagon bed as an annex.

From Cugnot's invention we jump to that of William Murdock, which was responsible for the first propulsion on land in England. Murdock was James Watt's assistant, and as Watt was known as a somewhat bigoted opponent of the high-pressure engine idea, Murdock

Figure 2. The Trial Trip of Peter Cooper's "Tom Thumb," at Baltimore, August 28, 1830. The First Locomotive Built in America. From "Railroads Old and New," Verona Tool Works.

worked at night in order that his line of thought and his effort to produce a practical engine might not be known to his chief. His locomotive had a single vertical cylinder, the piston rod being connected with one end of a beam vibrating on a joint at the other. A connecting rod was jointed to the beam close to its working end and turned a crank in the axle of a pair of driving wheels. The cylinder was half-immersed in a copper boiler, through which a flue passed obliquely, the heat being supplied by a spirit lamp beneath.

All sorts of curious stories were told of the first appearance of Murdock's engine. It was said that people were "frightened into spasms" by the terror inspired when they saw it approach. As a matter of fact, it probably was far from terrific in its aspect, and certainly its speed could not have been great with the power generated by the heat of the small lamp.

The Field Columbian Museum owns the original cars and the original track which were used in connection with the "Trevithick," the first locomotive that ever ran on rails. The date of the Trevithick is the year 1800. Richard Trevithick is known as the father of the locomotive. The museum possesses a full-size working reproduction of this his first effort at locomotive building.

It has been said that because of the showing of "the non-necessity for condensing water, the cylindrical boiler, the simplest form of crank, the absence of mason work for engine and boiler flues, and because its portability and power of locomotion so nearly met requirements, this engine should be called the first high-pressure locomotive."

An idea may be gained of the extent of the exhibit in the hall of the "World's Rail Way" by barring minute

description and giving in order of invention and production the names, with a few words of description, of the steam power engines that followed the Trevithick. Such a list, however, in this article is necessarily limited to the more important inventions. There are nearly a score which must be passed. A large number of the engines and locomotives shown are the original machines, while all the others are working reproductions.

* * * * *

Following the second Trevithick, which came in 1802, we have the "Evans" of 1804 and the "Brunton" of 1812, which had legs to overcome the difficulty of getting sufficient adhesion. This engine looks not unlike a gigantic grasshopper. The Hedley engine, which followed the Brunton, first demonstrated the possibility of making progress with smooth wheels on smooth rails.

One of the most interesting engines to Americans in the entire exhibit is Peter Cooper's "Tom Thumb," which was the first locomotive built and the first to draw a car on the American continent. Then are shown in close order Stourbridge's Lion, Stephenson's Rocket, Hackworth's Sanspareil and Ericsson's Novelty.

The "Best Friend" was the first locomotive built in America for actual service. Peter Cooper's Tom Thumb made one or two trips, but they were in the nature of trials. The Best Friend in the museum exhibit is shown exactly as it stood years ago, when it accomplished its work to the amazement of the multitude.

"Old Ironsides," which was built by Matthias W. Baldwin in 1832—the name Baldwin is known today wherever a locomotive is shown—did duty for twenty years, and the engine as it stands in the Field Museum is i

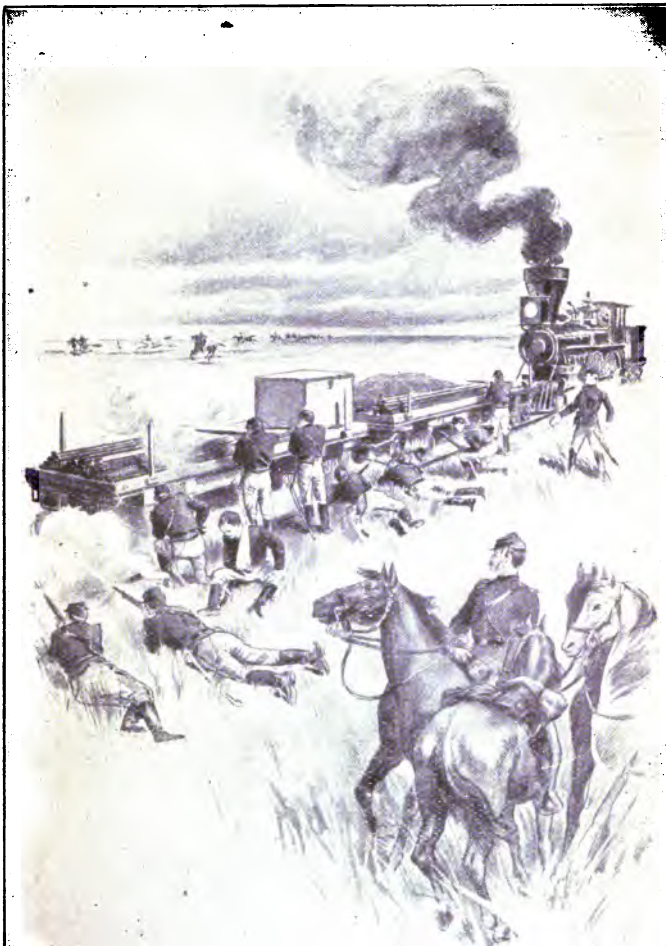

Figure 3. Pioneer Railroading in the West.
From "Railroads Old and New," Verona Tool Works.

nearly all its parts the original machine of two generations ago.

The original Rocket, built by Braithwaite & Co., of England, and imported to America in the year 1838, stands in the "Museum of the World's Rail Way," and has in it practically the same material that was put together by the British workmen of seventy years ago. This engine was the original No. 1 of the Philadelphia & Reading Railroad.

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The modern locomotive stands not many yards removed from Newton's crude invention. There are in the exhibit wheels, coaches, rails and appliances, showing the development of these auxiliaries of the steam locomotive.

It may not be out of place to say that this "museum of transportation" is one of the best practical aids to the student of steam and its application. The character of the exhibit is educational, and such it primarily is intended to be. It is in keeping with the spirit which has inspired the collecting and the arranging of all the material gathered for the benefit of the people in the departments of the Field Columbian Museum. The expression is old, but it means much—the Museum of the World's Rail Way is an object lesson.

In no industry perhaps does the United States enjoy a more remarkable ascendancy over the rest of the world, than in its railway service. At the close of the last century North America had no less than 220,800 miles of track in operation, while the total for Europe, Asia, Africa, Australia and South America was only a trifle greater—about 270,000 miles. The United States then had a mile of road for every 383 inhabitants, Europe one for every 2,267 and British India one for every 12,400.

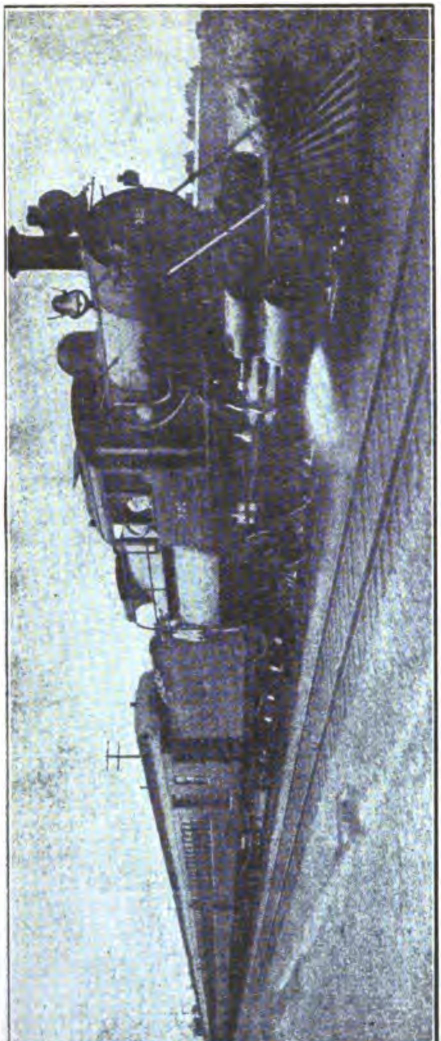

Figure 4. Modern Transportation.

This country invented the parlor, sleeping and dining cars, the pressed steel freight car, many of the best features of the modern locomotive, the air brake, the automatic coupler and a host of related devices and it runs the fastest long-distance trains.

One of the most marvelous developments in the whole railroad system is that which has taken place at the head of a train in the last seventy years. The best locomotives today are about four times as long as the De Witt Clinton (1831), a foot or two higher, have drivers that are 72 (or even 80) inches in diameter instead of only 54, and carry 200 pounds of steam instead of only 80. But these figures afford no idea of the real gain that has been effected in power.

Relative to the other features, the boiler has grown abnormally, while the smokestack has actually diminished in size. In the De Witt Clinton the smokepipe was as big as the boiler. One does not realize what modern science has done for this type of engine until he is told that it has a pull from 16 to 30 tons, as against 919 pounds. A locomotive built not long ago for the Santa Fé road weighed 133½ tons. Trevithick's engine, built just a century ago, weighed five! Stephenson's "Rocket" (1829) was several hundred pounds lighter. Even between 1850 and 1860 the average weight of a passenger locomotive was twenty tons and of a freight engine thirty.

ADVANCE OF AMERICAN LOCOMOTIVES.

One of the first advances in American locomotive construction was to mount the front end of the boiler by a stout pivot upon a small independent truck or bogie. Previously the forward wheels were secured to the whole

frame. That plan made the machine exceedingly rigid and awkward on sharp curves, where derailment often resulted. Another improvement was the "link motion" for reversing, for which the credit has been claimed both for an American, James, and for Stephenson. A more even distribution of weight on the wheels was secured by another Yankee notion, "equalizing levers."

"The locomotive is still in a state of evolution, and those who operate it are changing not only in the particulars of their duties, but in their aspirations and lives. The engineers and firemen of early days bore little resemblance to their brothers of the present period. The latter have not only personally acquired greater skill, but they possess also the accumulated experience of those who have gone before them. It is no exaggeration to say that the fireman of today, even if a novice, is much superior in capacity to the engineers who had charge for a long time after railways were first operated. The first enginemen were by trade blacksmiths and mechanics, who understood something about metals and machinery, but were ignorant of the uses of steam or the future possibilities of the locomotive. It was necessary to train men for the position. This process has been going on with ever accelerated speed from the first day up to the present moment. There is no end to the road. It grows wider and the horizon expands with each advancing step.

The firemen and engineers of railways constitute a highly trained class of men. Their knowledge and usefulness will increase with time and further experience. It is only reasonable to believe this because we know that possession of knowledge only intensifies the desires of men in this direction. Its acquisition by an ambitious

man creates an unquenchable thirst for further light. His mind expands with his opportunities in this direction until the vacuum of the brain appears so much greater than its filled space that the wisest man becomes despondent at the meagerness and superficiality of his knowledge. It is only the supremely ignorant man whose mind is at rest."

The evolution of the engineer has been no less remarkable than that of the powerful and vast "powerhouse on wheels" known as the modern American locomotive. Nor has the limit of either the man or the machine been reached. Hence greater ability, knowledge, experience and skill are absolutely essential, necessitating closer application on the part of the twentieth century enginemen.

This, in turn, makes necessary the specialization of the subject of locomotive engineering, and, on the part of intelligent, progressive men, the supplementing of their experience with special technical knowledge.

Men alive to the needs of the time, to the progress of events and the evolutions now taking place, will not fail to appreciate and profit by the information which follows.

*MALLET ARTICULATED COMPOUND LOCOMOTIVES.

"It may be of interest briefly to state that Mallet Articulated Compound Locomotives possess the following combination of distinguishing features, viz.: Two sets of driving wheels, each having an independent set of frames, cylinders, pistons, crossheads, connecting rods and valve gear, yet all under one boiler with a single firebox. The rear set of driving wheels is held in frames secured to the boiler and to the high-pressure cylinders, which are also fastened to the boiler. The forward set of driving wheels is held in frames which have a limited transverse motion about a pivot joining them to the rear frames. This pivot is located on the center line of the engine at a point about midway between the two sets of driving wheels. The forward set of driving wheels is connected to the low-pressure cylinders which are not fastened to the boiler, but hung to the forward section of the frames with which they swing transversely. The waist of the boiler is supported by sliding bearings which rest in turn on the forward section of frames, and spring stops are provided to prevent undue transverse motion.

"Steam is conveyed through rigid pipes to the high-pressure cylinders. After exerting its energy the steam is exhausted into a flexible receiving pipe through which it passes to the low-pressure cylinders. The final exhaust is effected through a second flexible pipe connecting the low-pressure cylinders with the exhaust nozzle in the

***Extracts from a paper read before the Engineers' Club of Philadelphia, March 21, 1908, by Grafton Greenough.**

Figure 5. The Mallet Articulated Compound Locomotive.

smokebox. Hence this type of locomotive comprises two complete engines with but one boiler, and possesses the advantages of compounding, without entailing detrimental complications, as the forward engine is practically a duplicate of the rear one, except that its cylinders and pistons are of sufficiently greater size to compensate for the reduced steam pressure. It is obvious that the high and low-pressure engines would exert equal tractive powers, providing the weights on both sets of driving wheels are the same. If, however, these weights are unequal, the tractive powers of the two engines should vary accordingly. Sometimes the number of driving wheels in the two engines differs.

Figure 6. First Double Truck Locomotive.

"The forward engine is designed to swing transversely, in order to divide what would otherwise be an abnormally long rigid wheel base into two short rigid wheel bases, thus providing for the negotiation of curves. To further facilitate curving, or to support overhanging parts and

steady the locomotive, leading and trailing pony trucks, or else carrying wheels, are sometimes used.

"The articulated locomotive of today is not the result of a sudden conception, but rather the culmination of numerous attempts to build locomotives of this type, as evidenced by efforts dating from the pioneer days of American railroading. A review of the more important efforts should assist in gauging the value of recent endeavors. In making this review, consideration will be given to the better known designs of double truck and articulated locomotives, otherwise if mention were made of all the devices which have been employed to enable locomotives to traverse curves, the limited time available would be entirely consumed thereby.

"The 'South Carolina,' built in 1831, by the West Point Foundry for Horatio Allen, was the forerunner of the articulated system, yet this effort to distribute the weight of a locomotive over a number of wheels, and retain flexibility was too great a problem for that time.

"This engine was designed to correct evils that could have been avoided by simpler means. It demonstrated the fact that simplicity in design was of paramount importance if locomotives were to be kept in working condition without unduly taxing the repair shops. The improvement in road beds, strengthening of tracks and producing locomotives of simple design having a single pair of driving wheels, but quite well adapted to existing conditions, so occupied the attention of railroad managers that the articulated locomotive was temporarily abandoned.

"The basic factor controlling the hauling capacity of any locomotive depending on the frictional adhesion of the driving wheels to the rails, is the total weight on the

driving wheels, which is usually from four to four and one-half times the tractive power. Therefore an increase in tractive power demands a corresponding increase in weight on driving wheels and thus adds to the weight of the engine as a whole. It is understood that by 'tractive power' is meant the total force exerted by the engine at the rails; it is the sum of the draw-bar pull plus the force absorbed in moving the engine. The weight on the driving wheels multiplied by the coefficient of friction between driving wheels and rail is the limit of effective tractive power, for, should this limit be exceeded, the driving wheels would slip on the rails and ineffectually revolve. The coefficient of friction, with wheels and rails in good condition, is usually between two-tenths and twenty-five hundredths.

"The 'ratio of adhesion' is the ratio between tractive power and total weight on driving wheels at the rails; thus if the latter is four or four and one-half times the former, the ratio of adhesion is four or four and one-half respectively. The ratio of adhesion should be at least the reciprocal of the coefficient of friction between the driving wheels and the rails.

"Rails will support but a limited weight per wheel, so it follows that when the tractive power required of a locomotive causes the weight per wheel to exceed the carrying capacity of the rails, additional wheels are necessary to subdivide the load. The addition of wheels in a continuous frame lengthens the rigid wheel base of a locomotive. The amount by which the wheel base may be increased depends upon the radius of the sharpest curve to be traversed by the locomotive.

"To obtain flexibility, both on curves and on rough tracks, numerous devices have been employed, including

equalizing systems, two, four, and six-wheeled swing trucks, flexible beam trucks, journal boxes with extraordinary side play, tires without flanges, and again in an improved form the articulated engine.

"Practically no attempt was made to improve Horatio Allen's design until over thirty years had elapsed, when an energetic Irish engineer, named Robert F. Fairlie, brought out the design of an articulated locomotive which bears his name. Fairlie, who was an earnest advocate of narrow gauge railroads, especially where road building was expensive, had recourse to articulated locomotives to make transportation over such roads possible with minimum outlay for grading and reducing curvature. Fairlie 'double enders' as they were familiarly called, may be likened to a combination of two independent locomotives. the boilers of which are placed back to back and supported on more or less elaborate framing, whilst the two engines, including separate frames, running gear, and cylinders, form independent trucks free to swivel about the center pins on which the boilers rest. A good example of the Fairlie system of running gear is obtained by imagining the substitution of steam for electric motors on both trucks of a double truck electric car. These Fairlie locomotives proved too flexible for other than slow service, thus their usefulness was confined to crooked mountain roads where speed was not a consideration. Even under such conditions when working hard, the component engines, owing to their short wheel bases, would oscillate or 'nose' from side to side, the flexible steam pipes carrying steam at boiler pressure would continually leak, and when working at full capacity the driving wheels of either one or the other engine would often slip at critical times unless the ratio of adhesion was abnor-

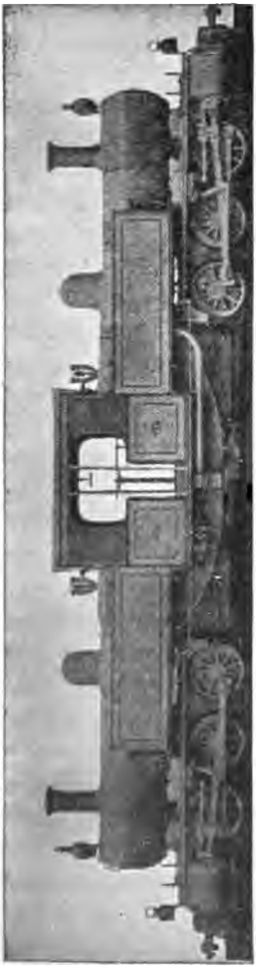

Figure 7. Fairlie Type Locomotive for the Burma Railways Built by the Vulcan Foundry Co.

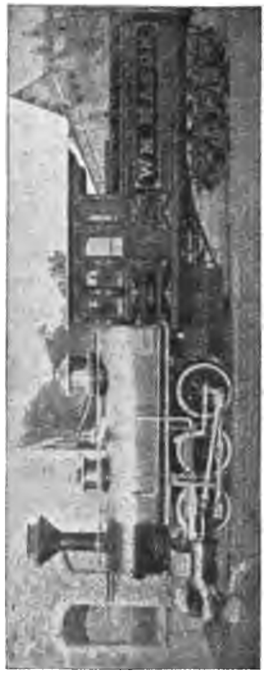

Figure 8. Mason Fairlie Locomotive, Built by Wm. Mason.

mal. Notwithstanding these defects, however, so great was the demand for flexible locomotives, that Fairlie type engines were introduced in various localities, and in many instances attained a reasonable degree of success. Modifications of this design have been made; sometimes the boilers have been joined, and in the 'Meyer' locomotive only one boiler is used. The arrangement of the double trucks in the Meyer system is not materially different from the Fairlie, except that the front and back frames are joined by a bar, and the front engine cylinders are occasionally placed at the rear of the driving wheels they operate. Some double truck locomotives of this type have been equipped with compound cylinders.

"Efforts were made to introduce these engines in this country, principally by Wm. Mason, who at first built close to Fairlie's designs. Later he built the 'Mason-Fairlie' double truck locomotives having but one boiler and one set of driving wheels which swiveled, also a rear truck which carried the water tank and fuel on the rear extension of the locomotive frames. These engines won many friends in their day.

"As late as 1890, some locomotives similar to the Mason-Fairlie design were built by the Baldwin Locomotive Works for the Mexican Central Railway. (See Fig. 10.)

"A double truck locomotive built by the Baldwin Locomotive Works for the Sinnemahoning Valley Railroad in 1892, was notable as being the first of the articulated type in this country to be equipped with compound cylinders of the Vauclain system. (See Fig. 9.) While inheriting many of its predecessors' faults, it was a step in the right direction.

"In the meantime Anatole Mallet, a Frenchman who

for years had endeavored to develop a successful compound locomotive, built about 1888, the first of the articulated locomotives which became known as 'Mallet Articulated Compound Locomotives.' At the expense of somewhat limiting curving ability, he inaugurated several important improvements which were destined to convert the articulated locomotive from a visionary scheme to a practical achievement. Instead of allowing the rear set of driving wheels to swing about a center pin, he secured

Figure 9. Double Truck Locomotive Sinnemahoning Valley Railway.

them laterally in line with the boiler, to which he permanently fastened the high-pressure cylinders, and delivered steam through fixed pipes, thus avoiding the use of high-pressure flexible steam pipes. This arrangement provides what may be termed a substantial foundation to which the frames of the forward set of driving wheels are pivoted, and avoids the lack of stability which is perhaps the most serious defect in the Fairlie system. The swing of the forward engine of a Mallet locomotive is limited to

suit requirements, and the entire driving wheel base of the locomotive is utilized to ensure transverse stability.

"A glance at the drawing (Fig. 12) shows that in both the Fairlie and Mallet types, pressure applied to the wrist pins tends to push the pins in the direction of the pressure, and unless the engine is on the dead center, to rotate the driving wheels to which the pins are attached. At the same time the reaction tends to move the cylinders and the frames to which they are fastened, in the opposite direction, which movement is necessarily in an arc about

Figure 10. Fairlie Type Locomotive, Built by the Baldwin Locomotive Works for the Mexican Central Railway.

the center pin or pivot by which the frames are fastened to the boiler or to each other. If pistons on opposite sides of the engine worked in unison, the turning action on one side would counteract that of the other, but as the wrist pins on one side are ninety degrees in advance of those on the opposite side, it occurs that through alternate quarters of each revolution the pistons on the opposite sides move in contrary directions, and hence tend to move the individual engine about the center pin or pivot to which it is attached, twice during each revolution of the driving wheels, once to the right and once to the left. All

engines have clearance between the rails, wheel flanges journal boxes, wedges and gibs and frames, therefore th engine is free to move transversely a distance equal to th

Figure 11. Mallet Type Locomotive, Built by the Swiss Locomotive and Machine Works.

sum of these clearances. Be fore the clearances are take up, transverse motion is re sisted by inertia, and by th friction due to the weigh on the journals and on th rails. The sum of the prod ucts of these resistance multiplied by the radii (y y', y'' and x, x) of the arc through which they act i the total resistance of th engine to transverse motion Consequently it is eviden that with the given weight per axles and equal rigid wheel bases this total resist ance is greater in the Malle type than in the Fairlie typ because of the longer aver age radius through which th resistance acts. In both type the reaction from the pres sure on wrist pins is tan gent to an arc with radiu (b or c) equal to the dis tance from the center pin o pivot to the center of cylin der in which line the pressure acts, and the moment o turning is the product of the reaction by the radius o

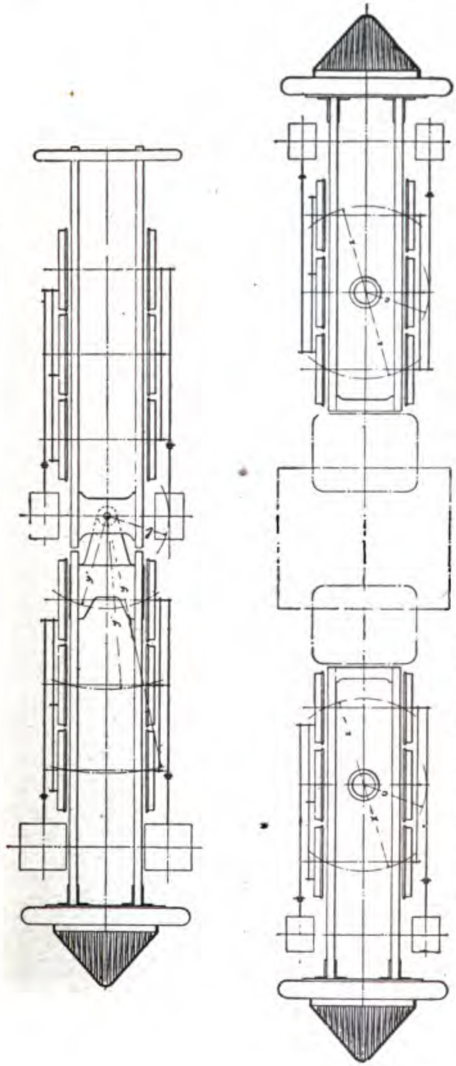

Figure 12. Plan View of Running Gear of Mallet and Fairlie Type Locomotives.

the arc through which it acts, and these moments are equal in engines of either type having the same total piston pressure and the same spread of cylinders.

"It therefore follows that the Mallet type is more stable transversely than the Fairlie type locomotive because with equal weight on driving wheels and equal rigid wheel bases it opposes a given turning moment by a greater moment of resistance to that turning.

"Transverse stability is of great importance because if the moment of resistance is not sufficient to eliminate nosing the engine will oscillate from side to side, causing the moving parts to wear rapidly, until the clearances are abnormal and the side motion too excessive for safety, and economy in maintenance.

"In Mallet locomotives no high-pressure steam is carried in flexible pipes, thus leakage at joints is practically avoided. It has been found that the low-pressure and exhaust pipes can be kept tight, whereas in the Fairlie type engines it is practically impossible to prevent leakage from such pipes under high pressure. The importance of this improvement is more keenly felt in cold climates where any considerable leakage causes the engine to be enveloped in a cloud of condensed steam and obstructs the view of the enginemen. It is to obtain this advantage that the low-pressure cylinders are made the movable ones. Thus the application of the compound principle, in addition to effecting an economy in fuel, removes a serious mechanical difficulty.

"Another advantage derived from compounding is the elimination of a tendency to slip the driving wheels. Unless the ratio of adhesion is especially high, all articulated locomotives having separate engines fed by independent steam pipes give trouble, because when working

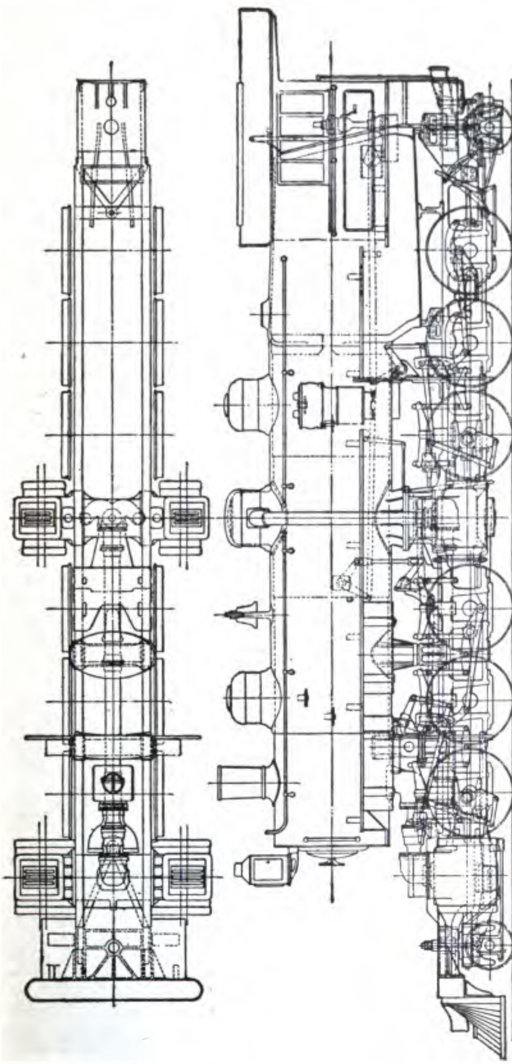

Figure 13. Side Elevation and Plan of Mallet Type Locomotive for Road Service Built by the Baldwin Locomotive Works for the Great Northern Railway.

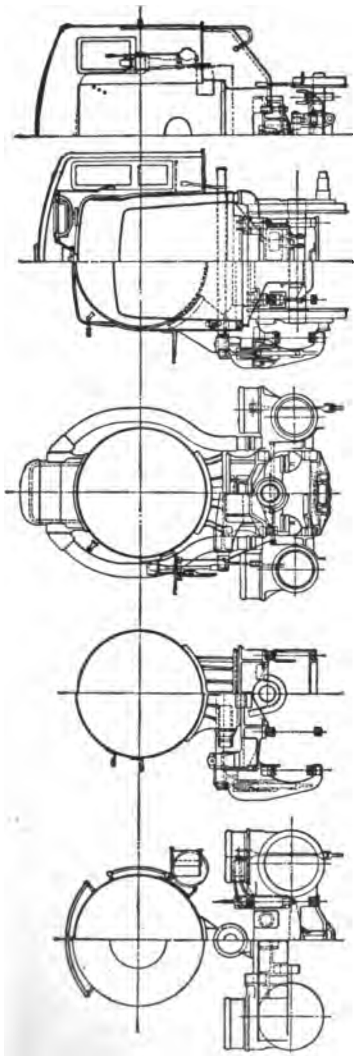

Figure 14. Cross Section of Mallet Type Locomotive for Road Service Built by the Baldwin Locomotive Works for the Great Northern Railway.

to full capacity it is found impossible to make both engines exert the same ratio of tractive power to weight on driving wheels, hence either one engine or the other will frequently lose adhesion and slip. On grades this often results in stalling the train before the loss in pulling power can be recovered.

"This trouble cannot occur with Mallet type locomotives, as in the event of slippage the locomotive immediately recovers itself, for the two engines depend one upon the other for the distribution of the steam. Should the high-pressure engine slip, its exhaust would fill the receiving pipe faster than the low-pressure engine could relieve it, and the resulting back pressure on the high-pressure piston would prevent further slipping. If the low-pressure engine should slip it would exhaust the contents of the receiver until the pressure in the low-pressure cylinders was reduced sufficiently to stop the slipping.

"Any continuous slipping can only occur in both engines simultaneously, which can be corrected by the same means that might be necessary for regular types of locomotives under the same circumstances.

"In addition to eliminating unnecessary flexibility Mallet simplified matters further by substituting one large boiler for two small ones; this not only reduced the integral number of parts comprising the boiler, but also provided one instead of two fires to be cared for. Mr. Mason also built articulated locomotives with one boiler, but in such cases only one set of driving wheels and cylinders was used, thus practically halving the capacity of the locomotive of given weight.

"The boilers of Fairlie, Mason and other double truck type locomotives rest on center pins, consequently

the stability of these engines is not affected by curving, while on the other hand, Mallet locomotives, having the boilers always in line with the rear set of driving wheels, are not so stable on sharp curves, as the forward set of driving wheels swings out of line with the center of the boiler to one side or the other. It is therefore apparent that curves might be sharp enough to cause the forward driving wheels to swing from under the boiler sufficiently to destroy equilibrium. While this limitation does not apply to conditions generally prevailing on standard gauge roads, it sometimes renders the Mallet type locomotive unsuitable for narrow gauge roads where excessively sharp curves prevail.

"To provide for curving, the boilers of all articulated locomotives must be placed high enough to allow the driving wheels to move transversely, hence the center of gravity of the boiler is necessarily higher than in types of locomotives in which the driving wheels do not move from side to side."

"Some account of the advent and use, in this country, of the Mallet type locomotives will doubtless assist in estimating the value of the claims for their favorable consideration.

"The honor of building the first of these engines for an American road falls to the American Locomotive Company, which in 1904, constructed for the Baltimore and Ohio Railroad Company a twelve-wheeled Mallet type locomotive, having three pairs of driving wheels in each group, and a weight in working order of 334,000 pounds, all on driving wheels, (See Fig. 15). This locomotive was exhibited at the Louisiana Purchase Exposition and then placed in pushing service near Rockwood Junction, where its performance has attracted considerable attention."

"During the same year the Baldwin Locomotive Works built three meter gauge Mallet type locomotives for the American Railroad of Porto Rico, which weighed 106,000 pounds each. All of this weight is on the driving wheels, of which there are two groups of three pairs each. Aside from the unusual weight and hauling capacity for narrow gauge service, these engines are not required to meet exceptional conditions.

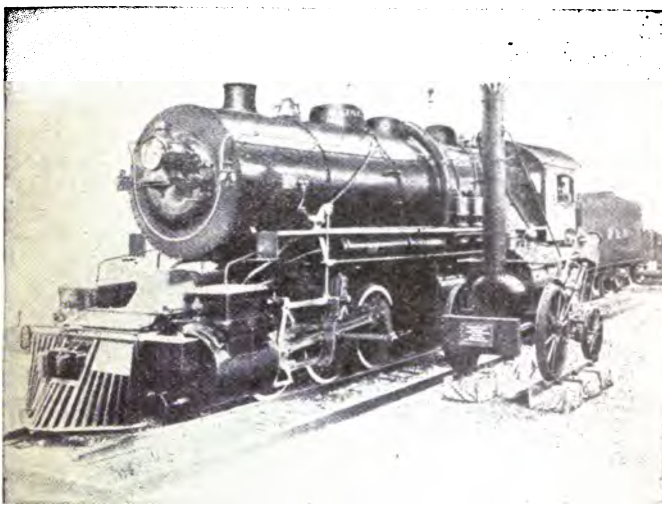

Figure 15. Mallet Type Locomotive, for Baltimore & Ohio Railroad, Exhibited at Louisiana Purchase Exposition.

"About a year later locomotives of similar type and size but for three feet six inches gauge were built for the Guayaquil and Quito Railway in Ecuador, where grades and curves are both numerous and severe.

"During 1907 the American Locomotive Company built three Mallet locomotives for the Erie Railroad. They

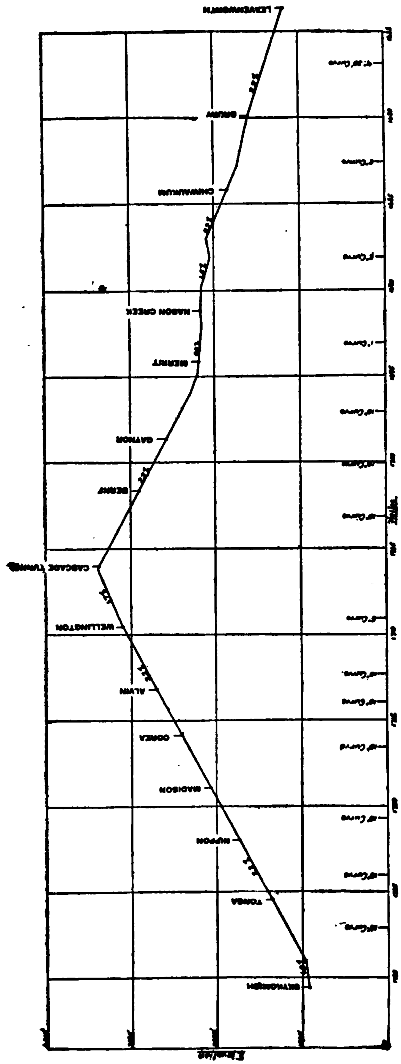

Figure 16. Profile of the Great Northern Railway Showing Grade Between Leavenworth and Cascade Tunnels.

Figure 17. Mallet Articulated Compound Locomotive Built for Great Northern Railway Co.

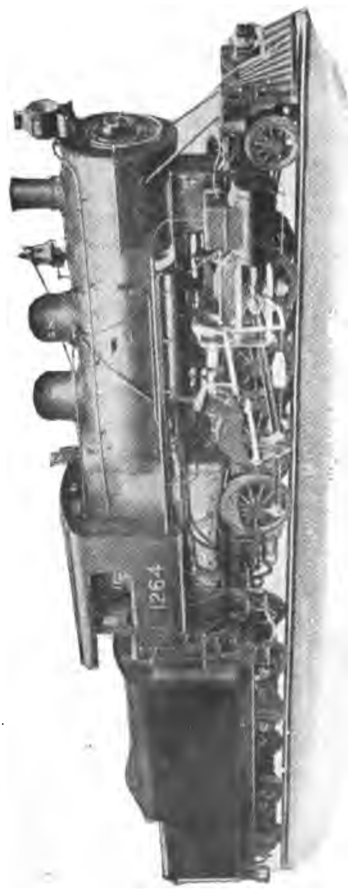

Figure 18. Consolidation Type Locomotive, for the Great Northern Railway.

are the heaviest engines ever built, their weight being 409,000 pounds, all on driving wheels, of which there are two groups of four pairs each."

"Designs carefully prepared by the Baldwin Locomotive Works for five Mallet type locomotives for the Great Northern Railway, resulted in the locomotives being used on grades of two and two-tenths per cent. in conjunction with curves of ten degrees."

"The engines were to push trains up the grade and "back" down for another load without turning, and the question as to how their vast weight could be made to curve without excessive flange wear was a problem, the solution of which caused much thought and discussion. The question was solved by providing leading and trailing wheels in radial trucks, such as are used on rigid frame road locomotives. This feature of construction proved successful as notwithstanding the weight of these engines, which is 355,000 pounds, of which 316,000 pounds is on the driving wheels, they are remarkably easy on flanges and tracks. In the fall of 1906, these locomotives were placed in service between Leavenworth and Cascade tunnel, a distance of about thirty-two miles. Their rating on a two and two-tenths per cent. grade is 800 tons of cars and lading, and their usual duty is to take with a leading Consolidation locomotive, a load averaging 1200 tons in weight exclusive of engines and tenders. As the Mallet locomotives weigh with 8000 gallon tenders about 252 tons and the Consolidations with 6000 gallon tenders weigh about 157 tons, the weight of the entire train is approximately 1614 tons of which the Mallet engines handle 1057 tons or sixty-five and five-tenths per cent. of the total."

GENERAL DIMENSIONS

GAUGE	4′ 8½″
CYLINDERS	21½″ and 33″ x 32″
Valve	Balanced
BOILER—Type	Belpaire
Material	Steel
Diameter	84″
Thickness of Sheets	⅞″
Working pressure	200 lbs.
Fuel	Soft Coal
Staying	Vertical
FIREBOX—Material	Steel
Length	117″
Width	96″
Depth	front, 79½″; back, 76½″
Thickness of Sheets	sides, ⅜″; back, ⅜″; crown, ⅜″; tube, ½″
Water Space	front, 6″; sides, 5″; back 5″
TUBES—Material	Steel
Wire Gauge	No. 11
Number	441
Diameter	2¼″
Length	21′ 0″
HEATING SURFACE-FIREBOX	225 sq. ft.
Tubes	5433 sq ft.
Total	5658 sq. ft.
Grate area	78 sq. ft.
DRIVING WHEELS—Diam.	Outside 55″
Diameter of Center	48″
Journals	10″ x 12″

ENGINE TRUCK WHEELS—

Front Diameter	30″
Journals	6″ x 12″
Back Diameter	30″
Journals	6″ x 12″
WHEEL BASE—Driving	30′ 0″
Rigid	10′ 0″
Total Engine	44′ 10″
Total Engine and Tender	73′ 2¼″
WEIGHT—On Driving Wheels	316,000 lbs.
On Truck, front	19,000 lbs.
On Truck, back	20,000 lbs.
Total Engine	355,000 lbs.
Total Engine and Tender, about	503,000 lbs.
TENDER—Number of Wheels	8
Diameter of Wheels	36″
Journals	5½″ x 10″
TANK—Capacity	Water, 8000 gals. Coal, 13 tons

SERVICE—Freight.

"The saving in fuel these engines effect is remarkable. Careful tests show the unusual reduction in the amount of coal used per ton mile of forty-six per cent. as compared with the coal required for the single-expansion Consolidation locomotives, engaged in the same work.

"From trials of the first locomotives it was found, notwithstanding prevailing ideas to the contrary, that Mallet type locomotives, in addition to heavy slow work, could be used to advantage for heavy hauling in road service. In consequence twenty-five lighter Mallet locomotives were placed in road service on a division of

the Great Northern 197 miles long in which many grades of one per cent. occur." They have twelve driving wheels divided in two groups, front and rear truck wheels, weigh in working order 302,000 pounds with 263,000 pounds on driving wheels, and with 8000 gallon tenders make a total weight of 231 tons. They easily haul 1450 tons of cars and lading on the one per cent. grades, and where lighter grades permit, attain speeds of twenty-five to thirty miles per hour, thus making the same time as Consolidation locomotives in the same work, but with the advantage of doing more work and doing it cheaper per ton mile."

"The convincing proof of the results obtained is shown by the fact that the Great Northern Railway has in service seventy locomotives of the Mallet type.

"One of the first heavy Mallets was borrowed from the Great Northern by the Northern Pacific Railway for trial between Livingston and Bozeman Pass Tunnel, a distance of twelve and one-half miles with maximum grade of two and two-tenths per cent. and curves of from one to eight degrees, resulting in the Baldwin Locomotive Works building sixteen locomotives for the Northern Pacific Railway practically duplicates of the heavy Mallet type engines of the Great Northern Railway. These engines weigh 351,000 pounds in working order with 313,500 pounds on driving wheels, and with 8000 gallon tenders weigh 250 tons. They serve as pushers behind trains pulled by either Mikado type or Consolidation locomotives weighing respectively 258,000 and 186,000 pounds. The corresponding weights on the driving wheels are 203,000 and 166,000 pounds. The former with 8000 gallon tenders weigh 209 tons and the latter with 5500 gallon tenders weigh 149 tons." "It is

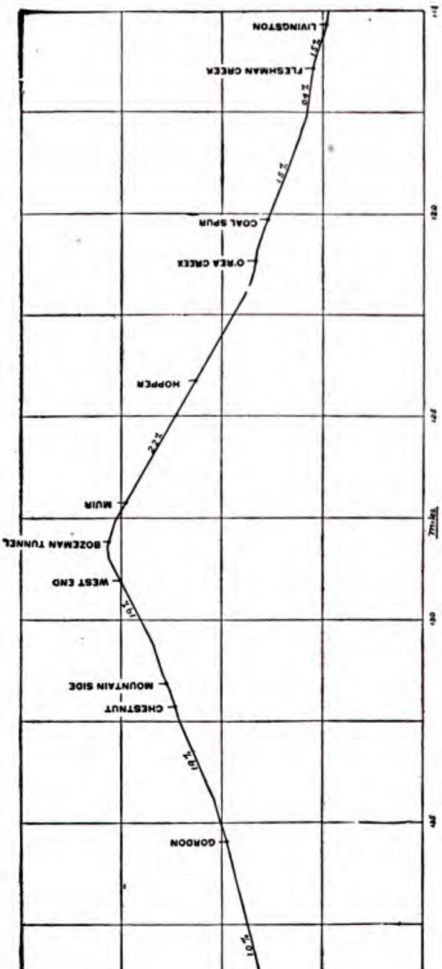

Figure 19. Profile of the Northern Pacific Railway, Showing Grade Between Livingston and Bozeman Pass.

learned that the rating on the heaviest grades is 850 tons of cars and lading for the Mallet locomotives, 600 and 500 tons respectively for the Mikado and Consolidation locomotives. In actual practice the Mallet engines usually handle from sixty to sixty-five per cent. of the tonnage."

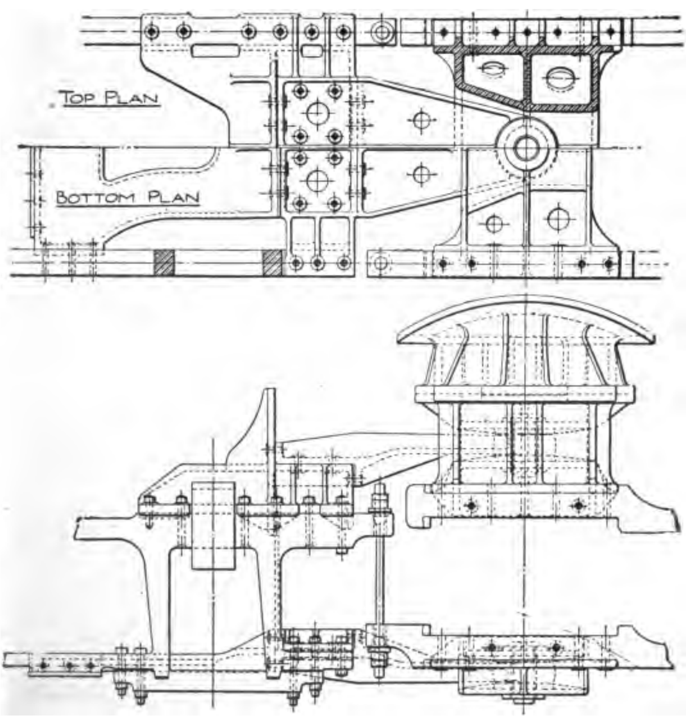

Figure 20. Articulated Frame Connection.

"Some of the mechanical details of the Great Northern and Northern Pacific Mallet locomotives are worthy of notice.

"The hinge connecting the two engines, although double and attached to both upper and lower bars of frames is a very simple device, which must necessarily be strong and firmly attached.

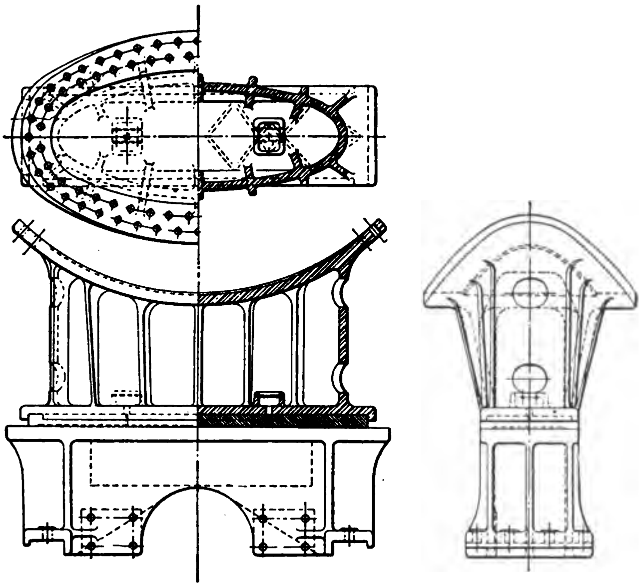

Figure 21. Sliding Bearing, under Front End of Boiler.

"The bearing slides on which the forward end of the boiler rests are of cast steel, the upper half being riveted to the boiler and the lower half bolted to the frame of the low-pressure engine; the bearing pieces are of cast iron.

"Thrust springs and their bearings are placed ahead of the bearing slides to regulate the side movement of the forward engine. These bearings are not intended to support the boiler.

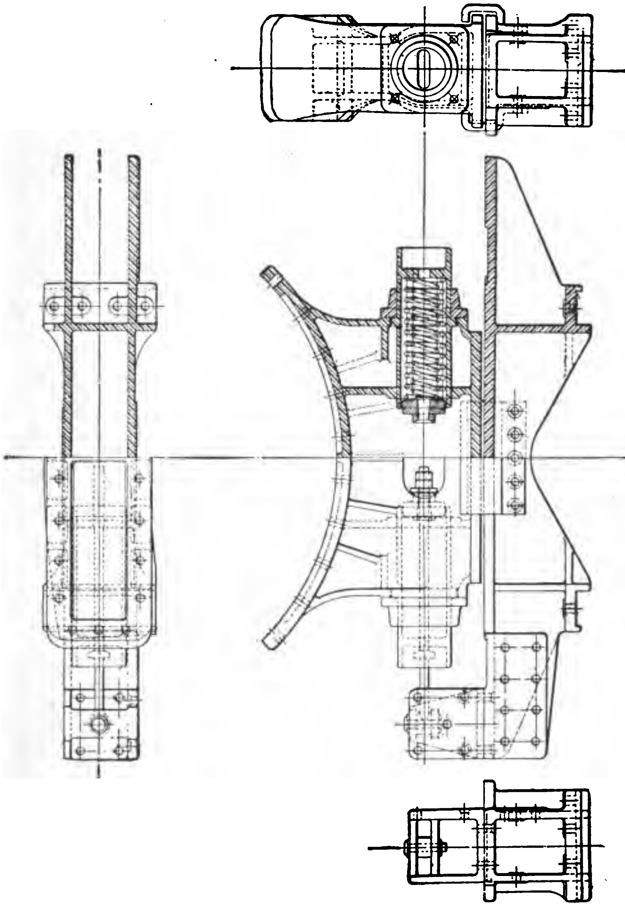

Figure 22. Thrust Springs and Bearings.

"The receiving pipe is easy of access for adjusting and packing, and is not at all complicated, having but one ball and one sliding joint. The exhaust pipe is similar in construction but has one additional ball joint.

These joints require but little attention in either pipe as they only carry low-pressure or exhaust steam and the tendency to leak is small.

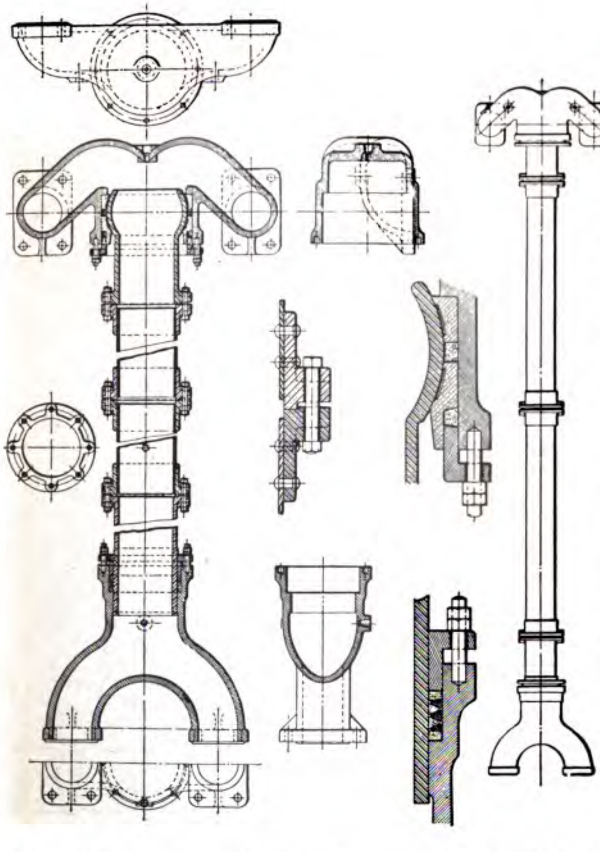

Figure 23. Receiving Pipe Connecting High and Low-Pressure Cylinders.

"In order to save room and restrict the height of the locomotives within certain limits, an ingenious combination of throttle and cast steel dome has been devised. The

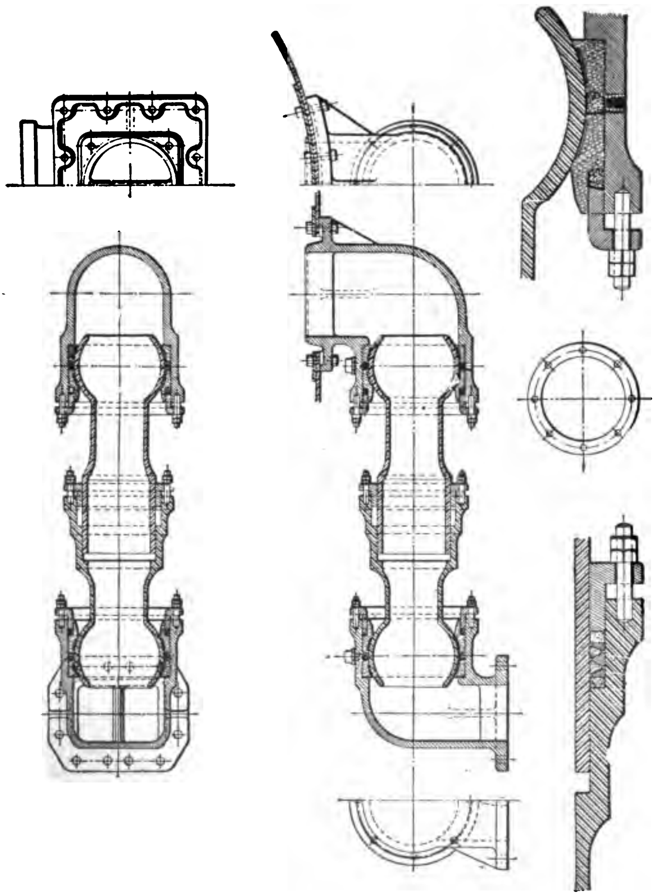

Figure 24. Exhaust Steam Pipe.

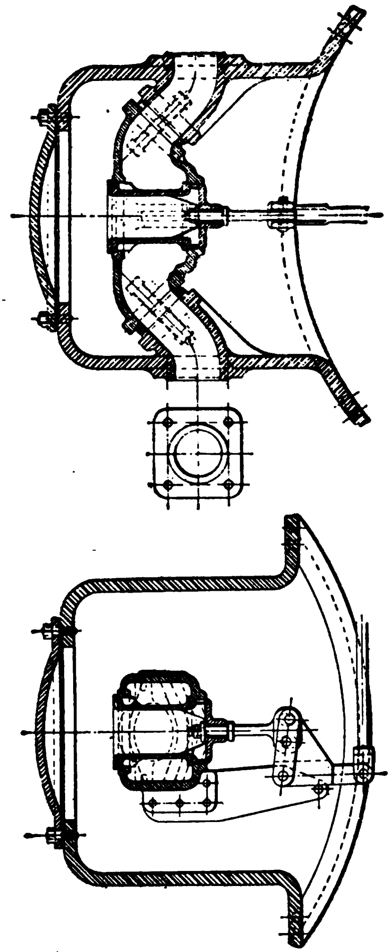

Figure 25. Steam Dome and Throttle.

valve box rests in elbows leading to the outside steam pipes.

"The reversing gear used on these locomotives is of the type patented by W. J. McCarroll, and is operated by compressed air. The engineer can easily handle the locomotive and adjust the cut-off without physical effort. The valve motions of both engines are connected to one reversing screw, and provision is made for reversing by hand if for any reason air pressure is unavailable.

"The steam chest valves are operated by the Walschaert valve gear, the use of which has become quite common in this country and requires no special comment. It is particularly advantageous on this type of locomotive because the eccentrics for the Stephenson valve motion could not easily be placed under the firebox, which is directly over the rear group of wheels.

"No complicated starting valves are required for these locomotives. If necessary steam can be admitted to the low-pressure cylinders through the receiving pipe to which it is fed through a suitable connection direct from the boiler. The supply of steam for this purpose is regulated by an ordinary pattern of valve. It is of course important that this valve should be closed as soon as the exhaust from the high-pressure cylinders is effective.

"Cylinder lubrication is provided by a four-feed lubricator with pipes leading to the high-pressure steam chests in the usual manner. The pipes leading to the low-pressure steam chests are provided with flexible connections to allow them to move with the forward group of wheels. It was found inadvisable to attempt to lubricate the low-pressure cylinders through the receiving pipe.

"The formula for calculating the tractive power of a two cylinder cross compound locomotive is also applica-

ble to the Mallet type, the result being multiplied b[y] two as the Mallet type has four cylinders. The formu[la] thus modified is as follows:

$$\frac{C^2 \times S \times 4/3\,P}{D} = T. \text{ where}$$

C equals diameter of high-pressure cylinders, in inche[s]
S equals stroke of high-pressure cylinders, in inches.
D equals diameter of driving wheels.
P equals boiler steam pressure in pounds.
T equals tractive power in pounds.

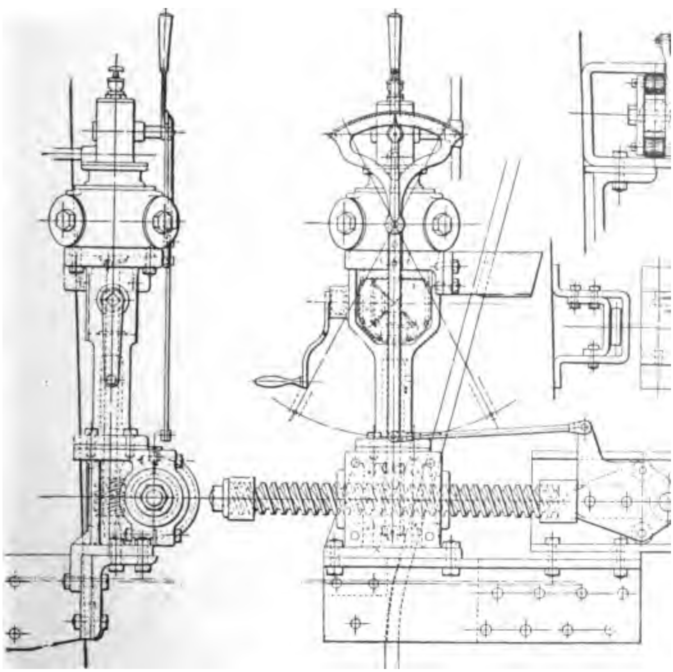

Figure 26. McCarroll Reversing Gear.

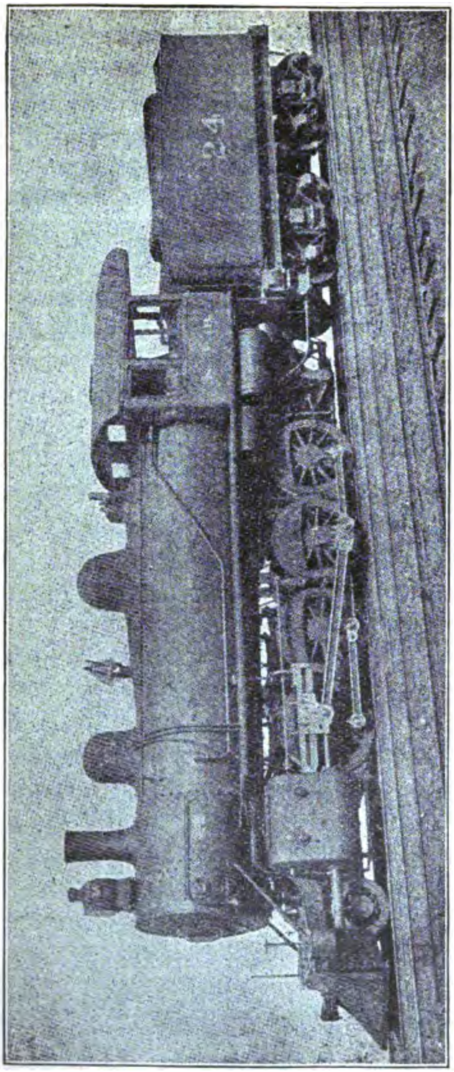

Figure 27. Compound "Consolidation" Freight Locomotive.

"The use of this formula is obviously based upon equal average total mean effective pressure on both high- and low-pressure pistons. In order to obtain this equality the ratio of the area of the high to the low-pressure pistons should be as 1 is to 2.4 with an allowable variation either way of 0.1.

"A careful consideration of the subject makes it evident that where rigid frame locomotives are adequate, the use of Mallet articulated locomotives is unnecessary. Where, however, on account of limiting conditions, a sufficiently powerful locomotive of ordinary type would not be practicable, the Mallet type frequently offers a satisfactory solution of the problem.

"When properly designed, Mallet type locomotives have pr6ved themselves practical, powerful, economical, flexible, and easy on the roadway, and indications point to an increase in their use."

CATECHISM ON COMPOUND LOCOMOTIVES.

What is the difference between compound locomotives and simple or ordinary engines?

A simple locomotive has only one set of cylinders and they are of the same diameter. The steam is used only once. Whereas in a compound the steam is used twice because it has two or four cylinders, (as the case may be) not of the same diameter. The steam passes through one cylinder where it loses part of its energy, then it passes into the second cylinder where its remaining energy is used. It is in fact using the steam expansively in a double expansion engine.

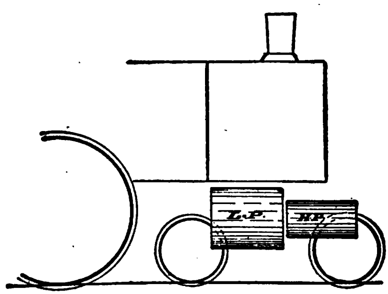

Figure 28.

Explain why one cylinder is called the high-pressure, and the other the low-pressure cylinder?

The steam enters the high-pressure cylinder directly from the boiler at nearly initial boiler pressure, and goes into the low-pressure cylinder from the high-pressure cylinder at a pressure much reduced, when the engine is working under ordinary conditions.

What are the main advantages of a compound supposed to be?

More work with the same amount of steam than can be done with a simple engine and a saving in fuel and water.

What is the object of the dash pot in a Schenectady two-cylinder compound?

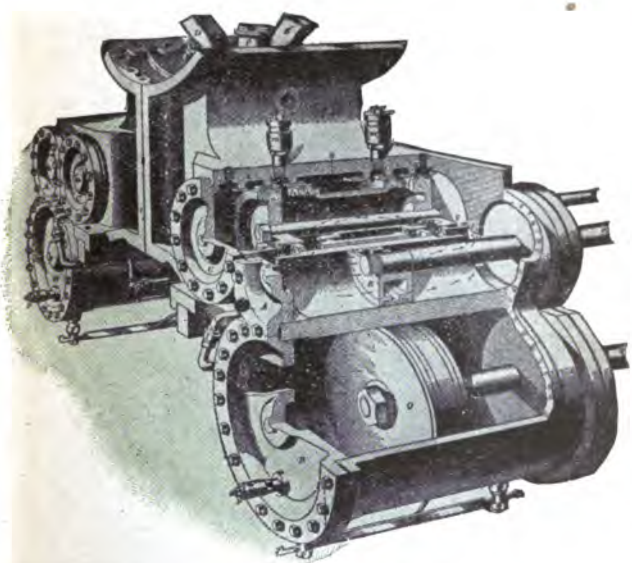

Figure 29. Cylinders and Saddle of a Vauclain Compound Locomotive

A—High-pressure cylinder; B—Low-pressure cylinder; C—Valve chamber; V—Piston valve; R—High-pressure piston; Q—Low-pressure piston; E—Steam pipe for left side of engine, branches in saddle, ending in chambers *g l*, surrounding valve bush; *kh* and *ji*—Steam-chest ends of passages *wx* and *ji* leading respectively to front and back ends of high and low-pressure cylinders; S—Passage leading to exhaust pipe P. Steam enters through *g* and *l*, filling both ends of steam chest; passes through *k* or *h* to high-pressure cylinder, and through *j* and *i* to low-pressure cylinder; thence through exhaust passage S.

It insures a steady movement of the valve without any shock.

Why should it be known that the dash pot has sufficient oil?

Because the dash pot should be kept filled with engine oil in order to prevent the slamming of the intercepting valve. Lack of oil in the dash pot often results in failure or breakage of the intercepting valve.

How may a Schenectady two-cylinder compound be operated as a simple locomotive?

The handle of the three-way cock must be moved so that air or steam pressure is admitted into the pipe which leads to one end of the separate exhaust chamber, in order to force the separate exhaust valve from the right to the left in the direction of the intercepting valve. Ordinarily the separate valve is held in its place by a spring, hence the reason for its being thus forced. Thus, as the throttle opens steam comes directly from the boiler into the passage connecting with the intercepting valve, forces it from left to right, and so allows the steam to pass through by the ports and passages, thence it goes through the reducing valve and into the low pressure steam chest, and at the same time steam is being admitted direct from the steam pipe to the high pressure cylinder. From the high pressure cylinder steam is exhausted direct to the atmosphere through the receiver and separate exhaust passage. But from the low pressure cylinder steam is exhausted direct to the atmosphere in the usual manner.

When is it necessary to operate a Schenectady compound as a simple engine?

In starting with a very heavy train, whenever there is danger of being stalled, and only at very slow speeds.

Why should it not be operated as a simple engine when the speed is greater?

Because there would result a waste of steam, an increased consumption of fuel, and an unnecessary wear and tear and consequent strain to the machinery of the locomotive.

How may a two cylinder engine be changed from a simple to a compound locomotive?

First the three-way cock would be returned to its normal position allowing the pressure to be withdrawn from the piston head of the separate exhaust valve. The compressed spring being released as the pressure is exhausted to the atmosphere forces the separate exhaust valve to its normal position and closes communication. The pressure in the receiver, owing to the exhaust in the high pressure cylinder, rises and forces the intercepting valve to the left, and that opens the passage through which the exhaust steam from the high pressure cylinder passes through the receiver to the low pressure steam chest. Live steam is shut off between the boiler and the low pressure steam chest by the movement of the intercepting valve to the left.

What is it that moves the intercepting valve in a two-cylinder compound?

Because of the different areas of the ends of the valve the intercepting valve is automatically operated by the steam pressure to which it is subjected.

In what way should a compound be lubricated?

While using steam two-thirds of the allowance for cylinder lubrication should be fed to the high pressure cylinder. But this rule should be reversed when drifting for long distances, because of the increased surface

which is exposed in the low pressure cylinder and also because of there being no steam in the cylinders.

Why should more oil be fed to a high pressure than to a low pressure cylinder?

Because some of the oil fed to a high pressure cylinder is taken by the steam to the low pressure cylinder. More friction is caused in the high pressure than in the low pressure cylinder by reason of the high pressure of the steam, so more oil is needed to offset it.

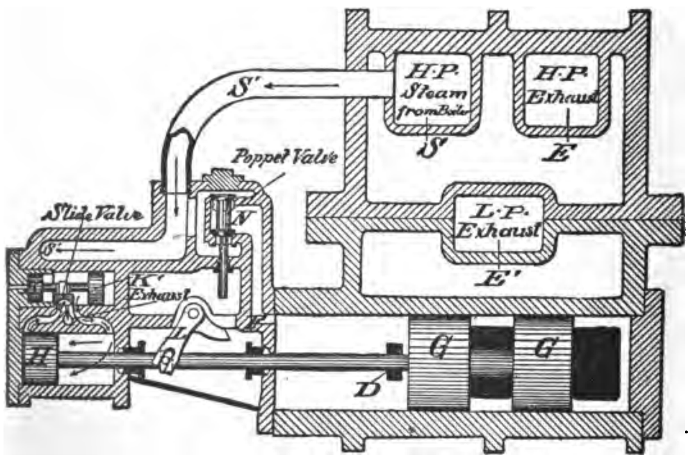

Figure 30. Intercepting Valve Open—Engine Working Compound.

In a boiler of a compound locomotive how much water should be carried?

Only enough to insure positive safety against overheating the firebox regardless of the different service conditions.

Why only enough water and no more than that should be carried?

Because only in that manner can delivery of dry steam be made to the cylinders. Wet steam should be prevented as it is very injurious to compounds.

With a long train to haul how should a compound be started?

In simple position; that is, it should be operated as a simple expansion locomotive.

What should be the position of the separate exhaust valve, cylinder and port cocks, when the locomotive is drifting?

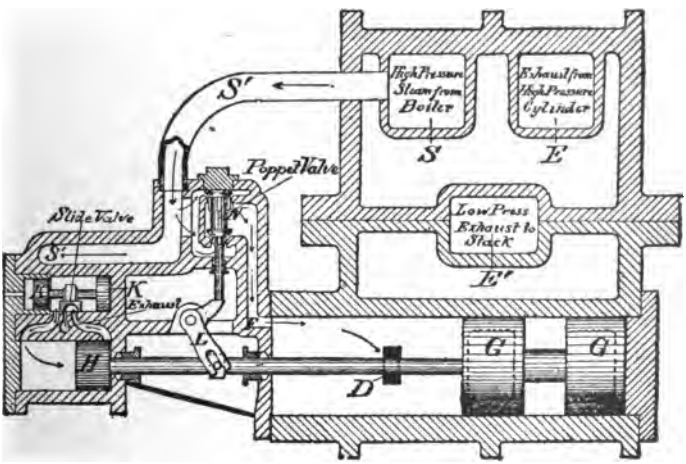

Figure 31. Intercepting Valve Closed—Engine Working Simple.

The three-way cock in the cab should be in the position for working simple, thus causing the separate exhaust valve to open and the cylinder port cock should also be open.

When the engine is being changed to compound what will cause two exhausts of air to blow from the three-way cock?

The exhaust valve spring may be loose, or the exhaust valve may itself be sticking.

When steam blows at the three-way cock what does it indicate?

Exhaust valve seat leaking and steam passing by the exhaust valve piston packing rings.

If the engine will not operate as compound when the air pressure on the separate exhaust valve is released by the three-way cock, what can be done?

It usually results from the separate exhaust valve being stuck and so communication with the separate exhaust valve is not closed. A little headlight oil through the oil-plug at the three-way cock may be forced to the separate exhaust valve, and by repeating the operation shortly afterward with cylinder oil the valve may generally be released.

If the locomotive is standing and the high-pressure side is on the dead center, and when given steam will not move, where is the trouble likely to be; what should be done to get started and why?

A stuck intercepting or reducing valve preventing direct communication between the boiler and the low-pressure cylinder is most likely the cause of the trouble. Which valve is sticking may be known by the position of the intercepting valve stem, which would extend clear out if the intercepting valve were stuck. In that event a light tap on the end of the stem, after the throttle is opened, will send it ahead, unless some of the parts be broken. But if the reducing valve is stuck the stem will protrude only a few inches. In that case a few sharp blows on the intercepting valve back head, with the throttle opened, will usually start it and thus direct communication between the boiler and the low-pressure

cylinder will be once more effected. Because the intercepting and reducing valves by their relative positions to the openings in their valve chambers control or prevent the free admission of steam from the boiler to the low-pressure cylinder direct, anything that prevents the free movement of either valve renders both of them

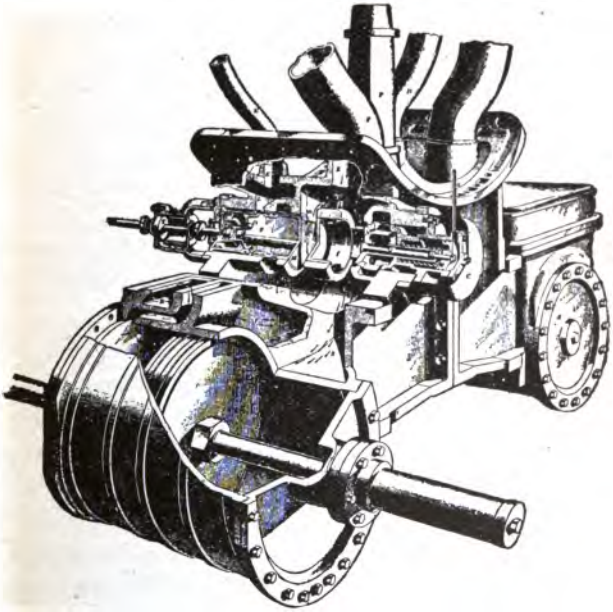

Figure 32. Valve Arrangement of Schenectady Compound Locomotive.

M—Intercepting valve controlling passage *mn* leading from chamber I to chamber G; N—Emergency exhaust valve controlling opening from I to emergency exhaust passage *c*; O—Reducing valve admitting live steam to G and regulating its pressure there; E—Small steam pipe leading to chamber L ending in passage surrounding one end of bushing of M; *e*—Chamber also surrounding intercepting valve bushing and opening into G; G—Chamber dividing into R and S leading respectively to back and front ends of low-pressure steam chest; F—Exhaust passage leading below G and behind I to exhaust pipe P; 6—Small pipe leading to operating valve in cab.

inoperative. If the admission of steam into the passage connecting with the intercepting valve cannot move it from its normal position, direct communication between the boiler and low-pressure cylinder cannot be established, and the greatly reduced power conveyed from the high into the low-pressure cylinder is insufficient to move the locomotive in starting.

How should disconnection be made in the event of a break-down?

The separate valve should be opened the same as for running simple; then block, cover the ports, and disconnect the same as for a simple locomotive.

To shut off steam pressure from the steam chest and low-pressure cylinder what should be done?

Place the separate exhaust valve and the intercepting valve position for working engine as a simple locomotive.

Is it important to pump up air on a Schenectady two-cylinder compound before starting, and, if so, why is it?

It is extremely important. It ensures a sufficient quantity of air pressure to operate the separate exhaust valve in order that the engine may be operated as a simple locomotive or single expansion engine.

How can blows be located in a compound locomotive?

Differently with different types. With two-cylinder locomotives blows or leaks through valves or cylinder packing are tested for the same as for simple engines, the locomotive being worked as a simple while making such tests. For blows in the intercepting valve, the right-hand crank pin is placed on the top quarter and the reverse lever put in the center of the quadrant, the intercepting valve is closed, and the separate exhaust valve is opened the same as when working simple. Steam

passes through the separate exhaust valve and appears at the exhaust nozzle if it is the intercepting valve which is blowing.

To what ports are the by-pass valves connected, and why are they used?

To the steam ports, and they furnish communication between the steam chest and the steam ports in the cylinders. They are used to relieve the cylinders from excessive back pressure when drifting.

Why are the four-cylinder Schenectady compound locomotives in service called tandem?

Because the high-pressure cylinder is ahead of and connected with the low-pressure cylinder, and both pistons are operated by the same piston rod.

Does the steam in a tandem compound locomotive exhaust from left to right cylinders in a similar manner to the Cross compound?

No, the steam from the high-pressure passes to the low-pressure on the same side.

Are the valves on a tandem compound designed to give outside or inside admission to steam?

The valves on a tandem are designed for both inside and outside admission.

What arrangement of steam ports have these engines, so that an outside and inside admission valve may be operated by one valve rod?

On the high-pressure cylinder the valves are arranged for internal admission, and the steam ports in the high-pressure cylinder are crossed. On the low-pressure, the valves are arranged for external admission and the steam ports are those in use on the ordinary type engine.

Trace the course of the steam from the high-pressure valve to the atmosphere when working compound.

As both valves operate on one stem, and as the high-pressure valve is internal and the low-pressure external admission, the ports in the high-pressure cylinder have to be crossed, so when live steam is admitted to one end of the high-pressure cylinder the exhaust from the opposite end of the high-pressure can pass over into the low-pressure cylinder to use its power in the same direction and in keeping with the high-pressure. Steam leaving the high-pressure valve and entering the back port in the high-pressure cylinder flows to the forward end of the cylinder and forces the piston back. After its force is spent it is exhausted to the high-pressure steam chest, passing through the center of the hollow high-pressure valve to the outer back edge of the low-pressure valve, enters the back end of the low-pressure cylinder, and after its force is spent escapes through the exhaust port of the low-pressure valve to the atmosphere direct.

When and how may a tandem compound be operated as a simple engine?

Only in starting or when there is a possibility of stalling. It can only be operated as a simple engine when the starting valve is used.

What steam passages have communication with the starting valves?

The high-pressure steam ports and the passages surrounding the by-pass valve.

How does the manipulation of the starting valves cause the engine to operate as simple?

The starting valve, which is operated by a lever in the cab, admits live steam directly to the low-pressure cylinder in the following manner: Steam is admitted to the high-pressure steam chest through the short steam

pipe connecting the saddle and the chest, passing through suitable ports and around by-pass valves which register with the high-pressure steam ports. The by-pass valves are held against their seats by the pressure from below, which is in direct communication with the chest. The starting valve, having thus established communication with both high-pressure steam ports, steam passes through both hollow piston valves and is admitted to the low-pressure cylinder.

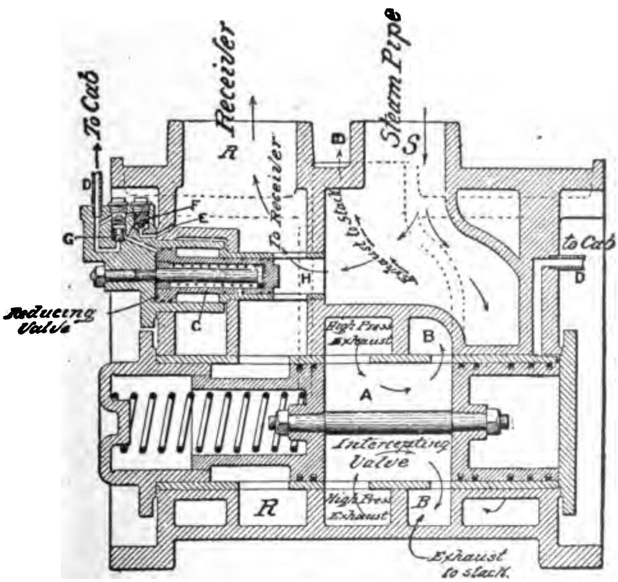

Figure 33. Baldwin (or Vauclain) Two-Cylinder Compound Engine Working Simple.

What other valves are in the starting valve casting? The by-pass valve.

How many sight feeds to lubricators of a tandem compound, and what do they lubricate?

There are generally two lubricators each with a double sight feed and each sight feed lubricating only one of the four valves and pistons.

How should the oil used be distributed?

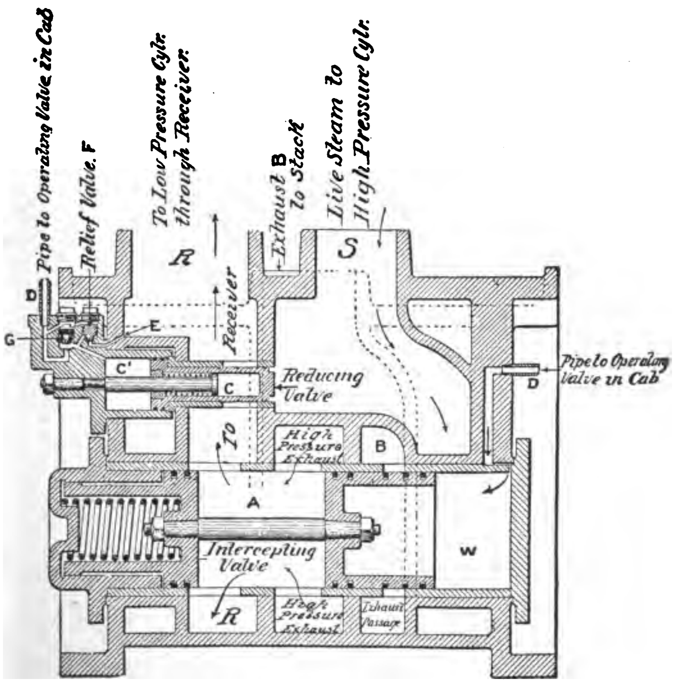

Figure 34. Baldwin (or Vauclain) Two-Cylinder Compound Engine Working Compound.

When the engine is working, the high-pressure should receive the greater and the low-pressure the lesser quantity, and when drifting these proportions should be reversed.

How should a Schenectady tandem compound be disconnected in case of break-down on the road?

Just the same as a simple engine with reference to blocking crossheads, covering ports, and the like.

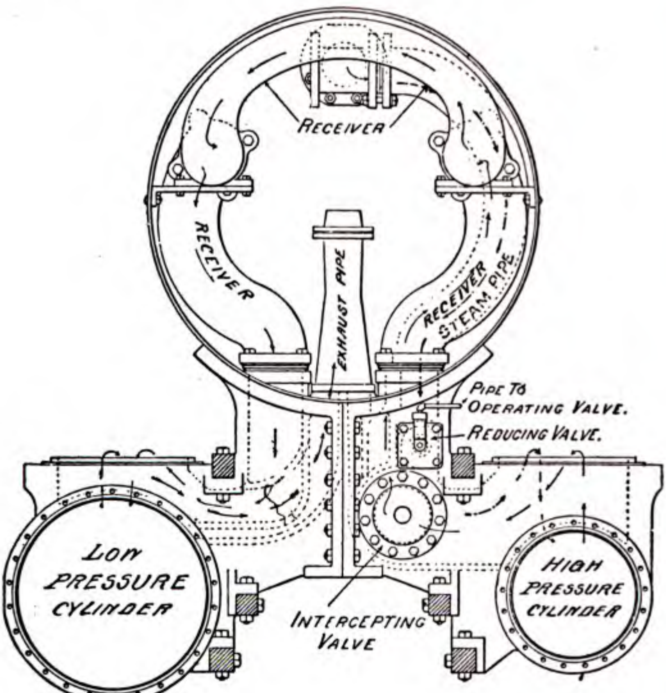

Figure 35. Baldwin Two-Cylinder Compound.

In a general way describe the arrangement of steam pipes, receiver pipes and cylinders in a two-cylinder or Cross compound.

The steam passes from the dry pipe through a steam pipe to the high-pressure cylinder steam chest. Ex-

hausts from that cylinder through a large low-pressure steam pipe called the receiver and extends around the inside of the front end to the low-pressure steam chest and cylinder on the other side of the engine, exhausting from there through the exhaust pipe and nozzle.

Regarding a Vauclain compound?

The steam and exhaust pipes are arranged as in a simple engine. The steam from the front side of the high-pressure piston exhausts to the back side of the low-pressure piston (on the same side of the locomotive). There is no receiver except that formed by the hollow piston valve.

Explain the difference between a four-cylinder tandem and a Vauclain compound in the arrangement of cylinders?

The tandem has one cylinder behind the other, the Vauclain Compound has one cylinder above the other.

How many main steam valves has a tandem?

Four.

How many has a Vauclain?

Two.

Why are the low-pressure cylinders made larger than the high-pressure cylinders?

To obtain the necessary area so that the less pressure will be equally as effective as the high-pressure cylinder.

Trace the passage of steam from boiler to atmosphere in a Vauclain compound engine, and state the difference when working simple.

Dry pipe to steam pipe, to steam chest, past the ends of the piston valve to the high-pressure cylinders; from there it is exhausted through the hollow piston valves to the low-pressure cylinder, thence it exhausts around the central outside cavity to the exhaust pipe and nozzle.

When working simple live steam from the boiler is admitted through a small pipe direct to the low-pressure cylinder and exhausted as usual, the high-pressure piston having equal pressures on both sides and not being of any effect.

In what position should reverse lever and simpling valve be when drifting down grade?

Lever in full gear, or nearly so, starting valve open for "simple."

With engines which do not have lubricator pipes extending to low-pressure cylinders, what should be done to lubricate low-pressure cylinder when drifting?

Work a little steam to keep them lubricated.

What device is provided on some engines for this purpose?

Oil pipes also leading to the low-pressure cylinders.

How would you test for valve blow in a Vauclain compound?

Place valve in central position covering all ports, open the throttle which admits steam to the ends of the valve. If the two extreme end rings leak, steam will blow steady from the high-pressure cylinder cocks. If the two inside rings leak, there will be a blow from the exhaust nozzle. The packing rings governing the low-pressure cylinder are best tested by placing the lever in the corner, starting valve open and brakes set. Steam would then blow through the exhaust.

How with a tandem?

Place the engine on the bottom quarter, block wheels, cover ports, remove the indicator plugs on the high-pressure cylinder, give the engine full steam. If tight, it shows that packing rings 2 and 3 are tight. To test the low-pressure valve, open the starting valve, replace

the indicator plugs in the high-pressure cylinder and remove those in the low-pressure cylinder; also remove the by-pass valve and screw the cap down. Open the throttle and any blow in rings 5 and 8 will appear at the exhaust.

How would you test for blow in high and low-pressure cylinder packing in each type?

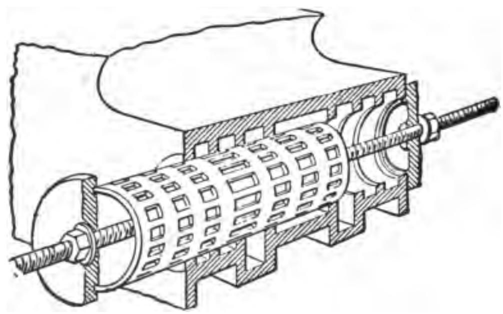

Figure 36. Valve Bushing and Method of Pushing in Baldwin (or Vauclain) Four-Cylinder Compound.

Both engines alike. In testing for high-pressure cylinder packing, place the reverse lever in the forward motion opening the front port to the high-pressure cylinder. With starting valve closed and indicator plug or safety valve open at the other end of the cylinder. Give the engine steam and if it blows it will be due to leaky cylinder packing or the No. 7 valve ring blowing. To determine which it is, make a similar test but with the reverse lever in the back motion. If still a blow, it is the high-pressure cylinder packing. If test for low-pressure cylinder packing, put the reverse lever in forward motion, remove only the back indicator plug from the low-pressure cylinder, open the starting valve and see if steam blows out of the plug hole.

How can a blow in sleeve between high and low-pressure cylinder of a tandem be located?

Shut the starting valve and admit steam to the back end of the high-pressure cylinder. If the steam blows, it will show at the front low-pressure cylinder cock or indicator plug and also blow through the exhaust.

How would you set a slipped eccentric on a Vauclain compound, or a tandem?

The same as with a simple engine.

In case it was necessary to disconnect on one side of a Vauclain compound, how would you cover ports and hold valve in position? How in case it was a tandem?

Place valve in central position in both cases and clamp securely, the same as with a simple engine.

At which end of guides would you block the cross-head, and why?

Back end, usually, because if it should get away the knocking out of a front cylinder-head is less serious.

How would you disconnect a Vauclain compound for a broken high-pressure piston rod? How for a low-pressure piston rod or piston?

If too heavy to take down, loosen the cylinder head, remove the indicator plugs and relief valves and run in slowly. Disconnect the valve on that side and clamp it in center.

Explain the working of a Vauclain compound with broken ring in high-pressure valve. Also in low-pressure valve.

A broken ring in the high-pressure cylinder will increase the pressure in the low-pressure cylinder on that side and consequently cause a heavier exhaust. A leak through the low-pressure packing will cause a blow and besides give a weaker exhaust than should be.

How would these defects be detected?

By testing for blow in cylinder packing.

Is there any difference in a broken front or back ring?

No.

What is the disadvantage of working a compound engine simple for long distances or when unnecessary?

Loss of fuel, excessive strains and wear, and it would make the engine logy.

Why is it necessary to sand the rail before starting a compound engine?

Because of greater liability to slip due to the greater power when temporarily working simple in starting.

Is it a disadvantage to work a compound engine at short cut-off, and why?

Yes, on account of excessive compression and because the work of the two cylinders is best equalized with the lever at about one-half cut-off.

When engine is working under partial load, how should reverse lever and throttle be operated as compared with a simple engine?

About half stroke and only as light a throttle as required.

Why is it more important to have cylinder cocks open when starting a compound engine than when starting a simple engine?

The cylinders are larger and there is greater liability of doing damage with water in them.

OIL BURNING LOCOMOTIVES.

Up to 1901 the use of oil as fuel for locomotives in the United States was quite limited; but the recent discovery of the great petroleum fields of Texas and Southern California has so increased the visible supply that oil is now much more widely used in this country than it formerly was. Oil versus coal as fuel is in fact one of the live, practical railroad problems of the day. All roads have considered this problem in a more or less systematic way, and not a few have to a greater or less extent equipped their lines with oil-burning locomotives, oil supply tanks, and other requisite mechanical appliances for the use of oil as fuel. The up-to-date railroad man, therefore, must know all about the oil-burning locomotive—how it differs from the coal burner, how it is fired, how operated, etc.

Petroleum, or "rock oil" as it was at first called, was discovered in commercial quantities in the United States about 1859. Very soon afterwards, experiments were begun, to find some practicable way of using the new product as fuel for locomotives. The first devices were very crude. For example, in two locomotives built for the Eastern Railway of France, the oil was simply allowed to run freely in grooves on the top of the grate bars, which sloped toward the front of the firebox, and the air supply came up between the bars in just the same way as when coal is used.

The first really successful oil-burner was made in Russia. It was invented by Thomas Urquhart, Locomotive

Superintendent of the Grazi-Tsaritzin Railway, about 1883. This device was one of the first to use a jet of steam to spray or atomize the oil as it enters the firebox, and this same principle has been adopted in all the most successful burners that have since appeared.

Russia is the greatest oil-burning nation today. The use of oil as locomotive fuel has in that country become more general than in any other. This is due in the first place, to the abundant supply of fuel oil there available, but more especially to the peculiar qualities of the Russian oil, which make it particularly adapted for heating purposes. With the largest portion of American petroleum, 75 per cent is capable of being made into refined oil, leaving only 25 per cent of residues. In Russia, on the other hand, these figures are exactly reversed: only 25 per cent is made into refined oil, while 75 per cent is residues. And the residues are what is burned.

ADVANTAGES OF FUEL OIL.

The relative advantages of oil and coal as fuel, depend, of course, on the question of their relative cost in use. In estimating this cost, various things besides the price of the fuel have to be taken into consideration—such as the savings effected in repairs to engine and roadbed; in labor, cleanliness, and comfort; in lessened liabilities to damage suits from setting fires, etc.

One pound of oil will generate approximately as much heat as one and three-fourths pounds of coal; but when all economies are taken into consideration, it is estimated that

$$1 \text{ lb. oil} = 2 \text{ lbs. coal.}$$

From experiments made by the Baldwin Locomotive Works, the following formula has been deduced, by the use of which can be calculated the price one would have to pay for oil to make it the equivalent of coal at any given price:

$$\frac{\text{Cost of coal per ton} + \text{Cost of handling (say 50c.)} \times 10.7 \times 7}{2{,}000 \times \text{Evaporative power of coal}} =$$

Price per gallon at which oil will be the equivalent of coal.

In using above formula, the cost of both coal and oil is considered *at the place delivered to the engine,* and not at the place where purchased by the railroad. By "evaporative power of coal" is meant the number of pounds of water evaporated by the boiler for each pound of coal burned; this varies considerably with the ratio of heating surface to grate surface, and with the volume consumed in a given time; and may range from 5 to 12 pounds.

Example:—If coal can be delivered to tender at $3.00 a ton, and oil would cost 1½ cents a gallon, or 63 cents a barrel of 42 gallons, which is the cheaper fuel? *Answer:*—Oil.

Using above formula:

Cost of coal	$3.00
Cost of handling	.50

$$\begin{array}{r} 3.50 \times 10.7 = \$37.450 \\ 10.7 \\ \hline 2450 \\ 3500 \\ \hline 37.450 \times 7 = \$262.150 \\ 7 \\ \hline 262.150 \end{array}$$

Now, suppose evaporative power of coal is 6.

$$2{,}000 \times 6 = 12{,}000.$$

$$\$262.150 \div 12{,}000 = \$.021 \text{ (or say 2 cents).}$$

```
12,000)262.150(.0210
       24000
       -----
        22150
        12000
        -----
         1500
```

That is, oil at 2 cents would be equal to coal at $3. If oil costs over 2 cents a gallon, coal at $3 a ton is the cheaper fuel; but if oil costs less than 2 cents a gallon, then oil is the cheaper fuel.

RELATIVE VALUE OF COAL AND OIL, ALL ASCERTAINED ECONOMIES CONSIDERED.

Oil per Barrel at	*Coal per Ton at*
$0 20	$0 65
30	98
40	1 30
50	1 63
60	1 96
70	2 28
80	2 61
90	2 93
1 00	3 26
1 10	3 59
1 20	3 91
1 30	4 24
1 40	4 56
1 50	4 89
1 60	5 22
1 70	5 54
1 80	5 87
1 90	6 19
2 00	6 25

The above table showing the equivalent values of oil per barrel and coal per ton, all economies being taken into consideration, has been prepared by the Baldwin Locomotive Works after careful investigation.

In performing calculations where relative weight and volume are concerned, the following table showing the equivalents of 1 pound, 1 liquid gallon, 1 barrel, and 1 gross ton, each in terms of the rest, will be found useful:

RELATIVE WEIGHTS AND VOLUMES.

Pound.	U. S. Liquid Gal.	Barrel.	Gross Ton.
1	.13158	.0031328	.0004464
7.6	1.	.02381	.003393
319.2	42.	1.	.1425
2,240.	294.72	7.017	1.

As already intimated, the conditions affecting cost of fuel oil have undergone changes in recent years. In 1900 the total production of crude oil in the United States was over 63,360,000 barrels, or nearly four times the production of 1888. In 1888, certain tests made by the Pennsylvania Railroad Company, as described by Dr. Charles B. Dudley before the Franklin Institute in Philadelphia, showed that at that time, with oil at 30 cents per barrel, it actually cost nearly 50 per cent more to take the same train of cars 100 miles by means of oil than by means of coal. Ten years later, however—or in 1898—the report of the Los Angeles Terminal Railway, with locomotives burning Los Angeles oil at 75 cents a barrel, showed that the cost per mile amounted to 11.1 cents, as against 28.3 cents, the average cost of coal for the year just preceding the adoption of oil as fuel.

The ordinary run of California crude oil will show in the calorimeter from 19,000 to 20,000 British Thermal Units, and an average evaporation of from 13 to 14 pounds of water per pound of oil, from and at 212° F.—an efficiency of about 80 per cent. The best coal obtainable will not run more than 13,000 to 14,000 B. T. U., with an evaporation of from 10 to 12 pounds of water per pound of fuel. Oil-firing can therefore get out of a boiler almost 25 per cent more power than coal-firing.

What the future holds in store for oil as a fuel, is not yet settled as regards the Eastern lines—those in the region of dear oil and cheap coal; but certainly, on the Western lines, oil-burning has now passed the experimental stage, and nothing short of exhaustion of the supply could turn its success into failure. The equipment of the Southern Pacific includes over 900 oil-burning locomotives. The Santa Fé has 315 on its Coast lines, and about 200 on its Texas lines. The Salt Lake Line has 75; and all the smaller lines in California are using oil as fuel exclusively. The total number of oil-burning locomotives in the United States in 1906 was estimated at 1,800.

The following are claimed as advantages of oil over coal as fuel:

(1) *Less waste of fuel.* With ordinarily constructed locomotives, working pretty hard and using a violent exhaust, it is cstimated that from 15 to 25 per cent of the coal escapes combustion, but with oil the combustion is practically complete.

(2) *Economy in handling fuel.* Oil can be run into tank on tender from standpipe, same as water, and supplied to firebox by turning a valve always within fireman's reach.

(3) *Economy in handling ashes.* With oil, there are no ashes to handle.

(4) *Economy in handling engines at terminals.* Estimated as at least 50 per cent less than the cost of handling coal-burners.

(5) *Diminished repairs to locomotives,* especially firebox repairs. It is only fair to note that in the case of oil-burning locomotives the firebox and flues are subjected to very severe punishment, and it is exceptional when

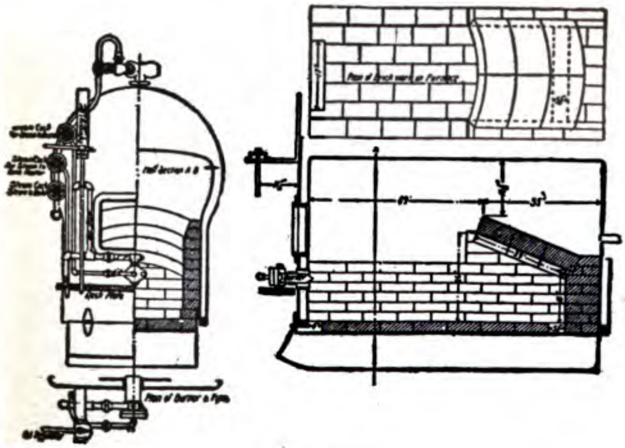

Figure 37. Details of Oil-Burning Furnace.

an engine will run two years without renewing firebox, or longer than twelve months with a set of flues. It is almost useless to attempt to patch side-sheets, for the heat is so intense that the extra thickness of metal prevents the heat from being taken up by the water, and the patch is soon burned. The side sheets in an oil-burner crack most frequently immediately back of the arch, evi-

dently because of the heat being most intense at that part of the firebox.

(6) *Economy in cleaning engines,* due to absence of smoke and cinders around engine.

(7) *Less waste of steam at safety valve.* It is estimated that in ordinary locomotive practice the waste of steam at the safety valve (which is equivalent to a waste of fuel) is about 5 per cent; but on an oil-burning locomotive, with proper care on the part of the fireman, there need be no waste of steam at all at the valve.

(8) *Economy in cleaning ballast.* Cinders thrown from stack in coal-burning locomotives, choke up ballast in roadbed, especially stone-ballast, interfering with drainage, and necessitating expenditure for cleaning.

(9) *Economy of space in storing and carrying fuel.* As the weight of oil used by a locomotive for a given distance is about one-half the weight and bulk of coal for the same distance, the use of oil effects a saving not only in space but in the dead weight hauled; or, with the same weight of oil as of coal, fuel for a much longer run is carried.

(10) *No fires from sparks.* In using oil, there are no burning sparks or cinders to set fire to buildings, bridges, or other property along the track.

(11) *Greater cleanliness and comfort for passengers,* owing to absence of smoke and cinders—a point appreciated by the traveling public, and tending to increase traffic.

(12) *Possibility of utilizing more of the heat.* Boiler flues must be large enough to avoid becoming choked up with cinders. In coal-burning locomotives, they range from 1¾ to 2 inches in diameter. If oil is used the flues may be made much smaller, and also be increased in number, thus increasing the extent of heating surface.

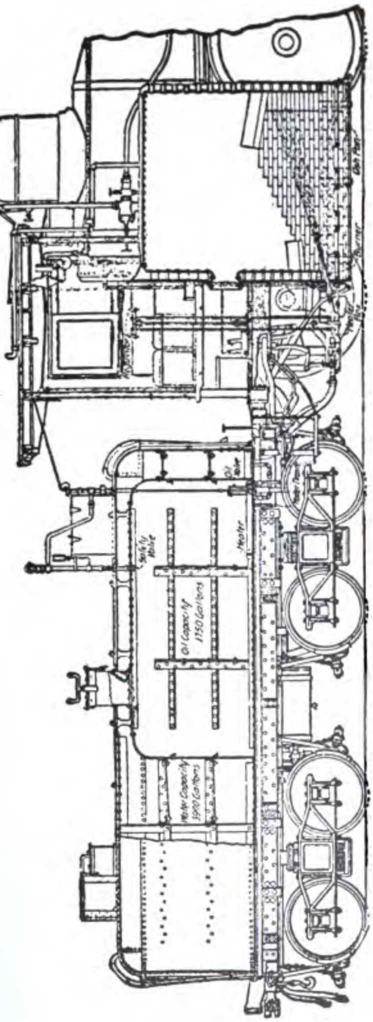

Figure 38. General Arrangement of Oil-Burning Locomotive—Santa Fe.

OIL-BURNING LOCOMOTIVES.

HOW CONSTRUCTED, FIRED, AND OPERATED.

In Fig. 38 is shown a coal-burner converted into an oil-burner. The positions of the various parts of the oil-burning fittings are indicated. The cost of converting a coal-burning locomotive into an oil-burner averages from $500 to $700, the chief item being the tender oil-tank, which has a capacity usually of from 2,000 to 3,500 gallons.

When a coal-burner is changed to an oil-burner the rates and grate frame are first removed. The ash par is then remodeled by putting in a casting which fits the inside of the pan, which is riveted on the sides near the top. This serves as a support for the brickwork of the sides of the firebox because it is cored out enough to admit just enough air for the proper combustion of the oil in the firebox. The brick arch is usually built as low as possible, the chief purpose being to protect the crown sheet, crown bolts and seams from overheating. The oil burner is secured to the bottom of the mud ring exactly central and is placed at an angle so the jet or spray of oil will strike just below or under the arch. Details of the arrangements of piping and brickwork of an oil-burning locomotive are shown in Figs. 37 and 48.

Ordinary commercial fire brick is used for side walls and inverted arch. Experience proves that fire bricks which soften under heat are preferable as they form a bond which adds strength to the wall and prevents it

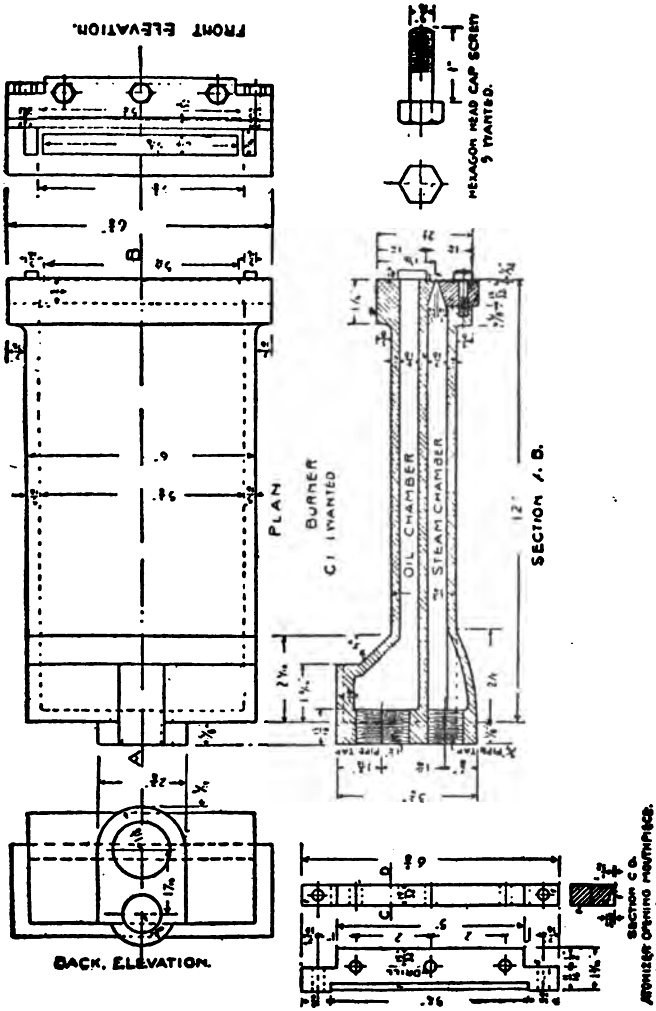

Figure 39. Details of "Booth" Oil-Burner—Santa Fe.

shattering under shocks. Fire bricks having very high heat-resisting qualities and claimed to crack when cooling are claimed to be of little use.

THE BURNER OR ATOMIZER.

One of the principal devices of an oil burning locomotive is the burner or atomizer, of which several designs are illustrated in Figs. 39, 40, 41, 42, 43 and 47.

Burners are of two general types, known as "outside" or "inside" mixers, according to whether the steam jet used for vaporizing or spraying the oil is brought into

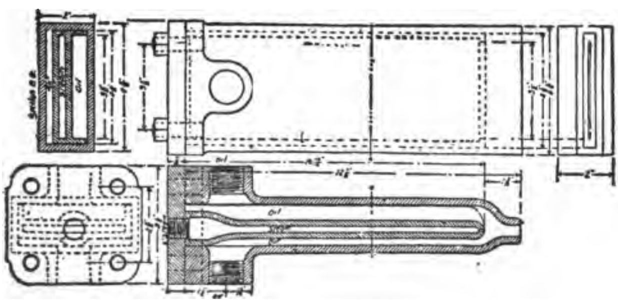

Figure 40. Details of "Sheedy" Oil-Burner—Southern Pacific.

contact with it in the air after both have left the burner, or whether this takes place inside the burner. Outside burners of the Booth type (Fig. 39) are used exclusively on the Sante Fé; and inside burners, 'Sheedy" type (Fig. 40), are standard on the Southern Pacific. The "Hammel" type (Fig. 41), used on the Salt Lake, is also an inside burner. Both types seem to give thorough satisfaction, so that the question which design to use does not seem to be of vital importance.

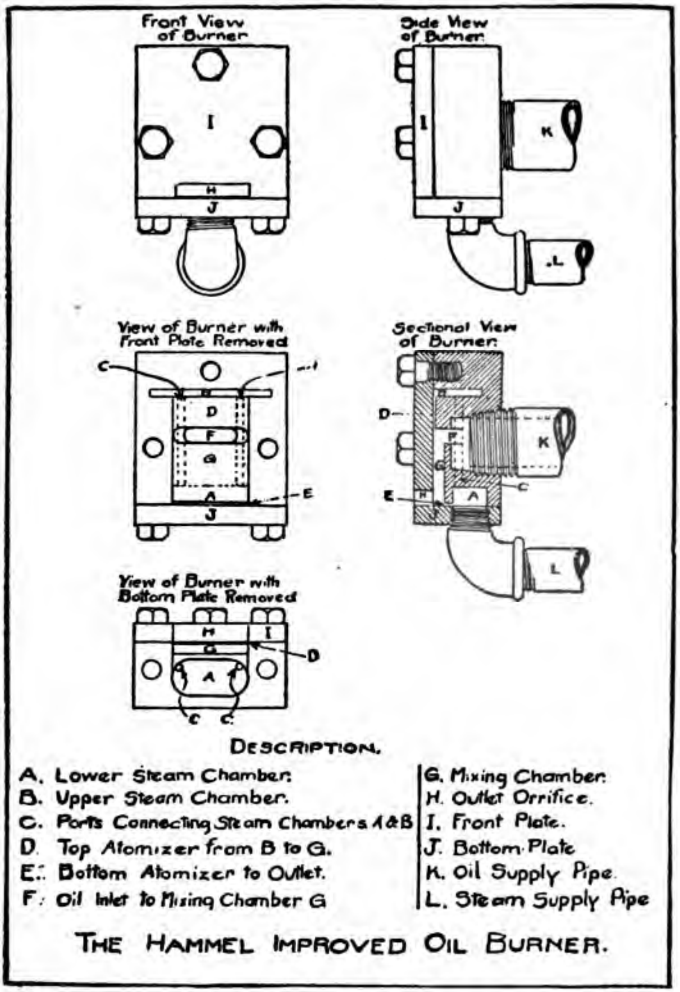

Figure 41. "Hammel" Oil-Burner—Salt Lake.

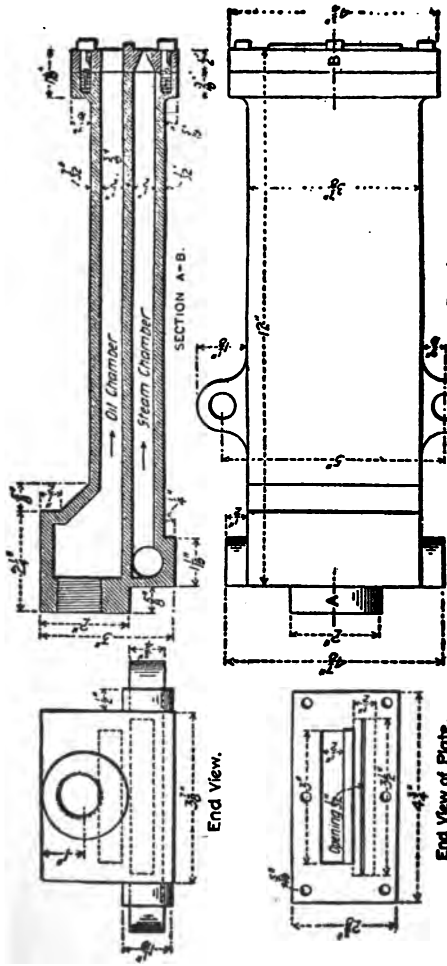

Figure 42. Details of "Booth-Wade" Oil-Burner. First Type Used in United States.

The purpose of the atomizer is to break up the oil into a fine spray. It is made of brass. In the Santa Fé burner (Fig. 39), steam enters bottom at one end and comes out through a slit at other end. The oil flows through the upper part of the burner over the hot partition and on issuing is caught by the steam and sprayed into the fire, which, when the engine is working, is a mass of flame

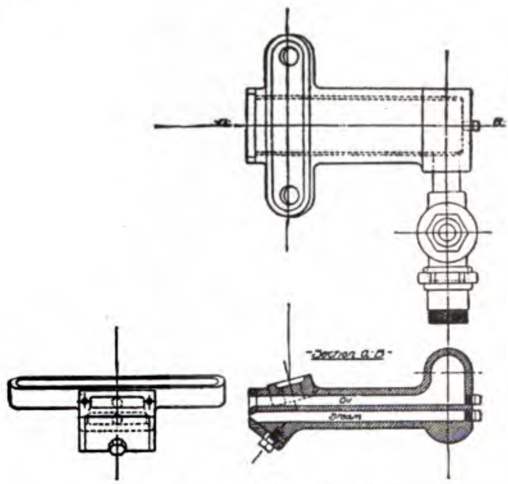

Figure 43. Baldwin Oil-Burner.

filling the firebox. The supply of steam and oil to the burner is regulated by the fireman from the cab, the handles of the steam and oil supply valves being located so that he can readily manipulate them from his seat.

The Santa Fé burner is rigidly attached to the mud ring; it is a casting having an oblong passage. One end of the casting is enlarged to receive connection with oil and steam pipes one above the other. The mouth of the

steam passage is directly underneath the mouth of the oil passage and the effect of the steam pressure is to spray the oil as it flows from the upper passage.

In the Southern Pacific burner (Fig. 40), there are three passages: one for oil, one for steam, one for air. Oil enters rear of burner from above, air is conveyed from below through a narrower passage to a common mouth just behind which terminates a central tube supplying steam. The mixture of oil, air and steam is there sprayed into the firebox through one nozzle. In the Southern Pacific arrangement the burner is located near the upper part of the bricked portion of the firebox, probably for the reason that the form of nozzle causes the spray to be thrown down as well as up.

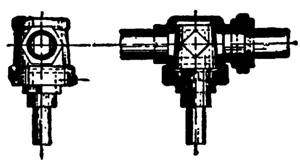

Figure 44. Baldwin Feed-Cock.

The opening in the plug, being square, retains its angular form and permits of very fine feed adjustment.

The type of burner used by the Baldwin Locomotive Works is rectangular in cross-section, with two separated channels (one above the other) running its entire length (Fig. 43). Oil from the reservoir is admitted through a pipe into the upper channel, its flow being controlled by a plug cock in the feed pipe, operated by a handle within easy reach of the fireman in the cab. Steam is admitted to the lower port of the burner through a pipe connected to the boiler in such a manner as at all times to insure the introduction of dry steam. The valve con-

trolling the admission of steam is also conveniently located in the cab close to the fireman's seat. A free outlet is allowed for the oil at the nose of the burner; the steam outlet, however, is contracted at this point by an adjustable plate which partially closes the port, and gives a thin, wide aperture for the exit of the steam. This arrangement tends to wire-draw the steam and increase its velocity at the point of contact with the oil, giving, it is claimed, a better atomizing effect. The plate after being once adjusted, need not be moved except for cleaning purposes. The oil, as it passes through the burner, is heated to a certain extent by the effect of the steam in the lower portion, and flows freely in a thin layer over the orifice. It is here caught by the jet of steam issuing from the lower port, and is completely broken up and atomized at the point of igniting. The oil is carried into the firebox in the form of vapor, where it is mingled with a sufficient quantity of oxygen from the incoming air to insure as near as possible perfect combustion.

The usual arrangement has been to place the burner at the *back* end of the firebox, using a brick arch; but latterly a design has appeared in which the same burner is used, but placed at the *front* end of the firebox. This does away with the need of the brick arch and thus effects a great saving of expense. For the maintenance of the arch is one of the heaviest of all expenses incurred in oil-burning. An arch costs originally about $25, and the life is in some cases as short as two to three weeks, and rarely exceeds three months. In Figs. 37 and 48 the burner is shown placed at *back* of firebox. Fig. 46 shows an arrangement adopted on some Santa Fé locomotives, with burner at *front* end of firebox, dispensing with the brickwork arch.

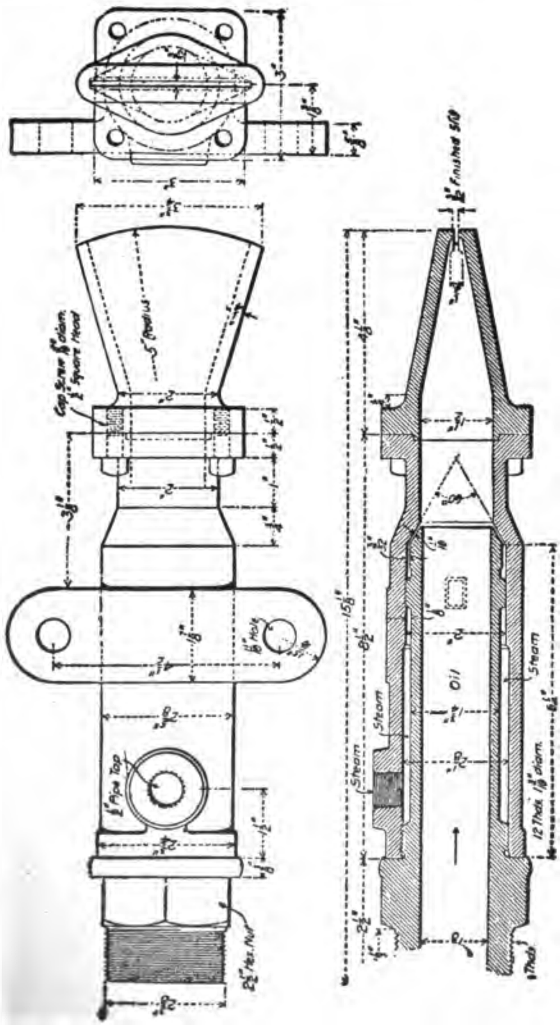

Figure 45. Details of "Lundholm" Oil-Burner.

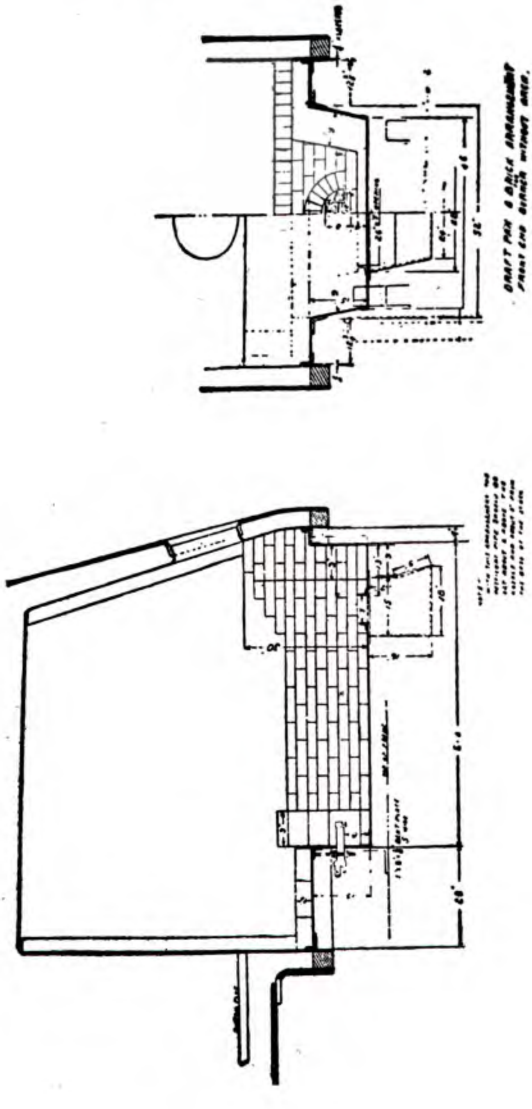

Figure 46. Oil-Burner at Front End of Firebox—Santa Fe

With the Lassoe-Lovekin burner (Fig. 47), a special type recently developed and tested on the Santa Fé Coast Lines—all brickwork is done away with, except a covering for the bottom of the ashpan. The oil is taken from the tank by means of a pump and delivered to the burner under a pressure of 120 pounds, being sprayed into firebox from back end.

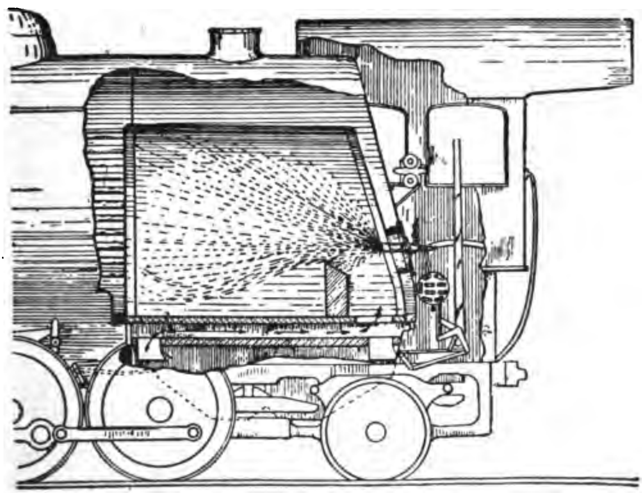

Figure 47. Lassoe-Lovekin Oil-Burner.
Dispenses with Brick Arch. Oil Supplied Under Pressure.

The general arrangement of the firebox as adopted by the Baldwin Locomotive Works, is illustrated in Fig. 48. The burner is placed below the mud ring at the back and on a line with the center of the boiler, and is pointed upward at a slight angle. A firebrick arch at front of firebox protects tubes and gives direction to heated gases, insuring their mingling with the incoming air. The

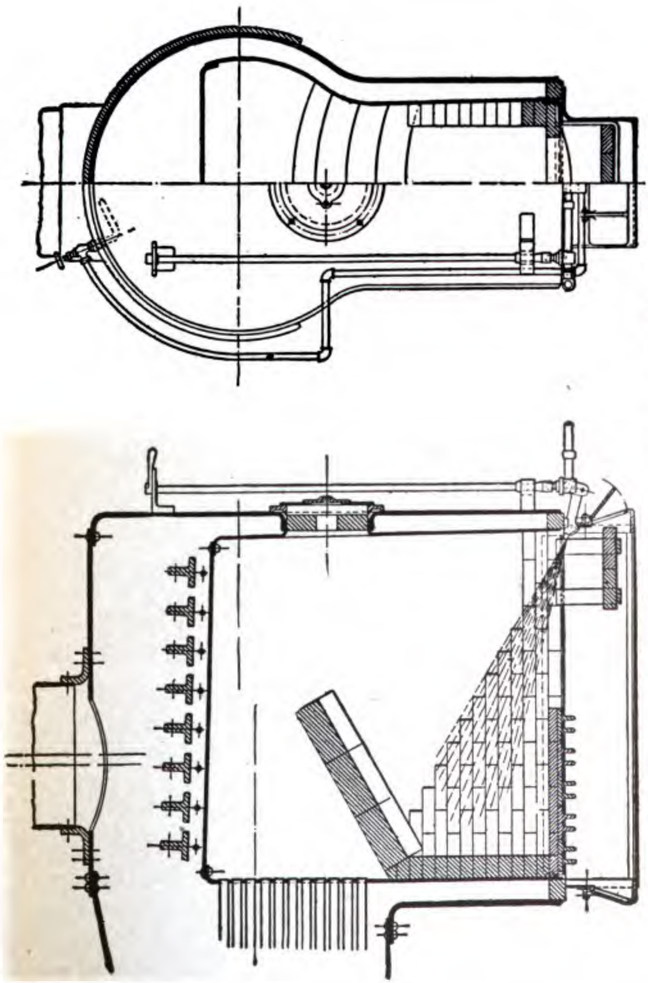

Figure 48. Burner and Firebox Arrangement on Baldwin Locomotive.

throat sheet below the arch is protected with a wall of firebrick. A layer of the same material is placed on the grate-bars (or equivalent supports), extending back from the front wall, and covering about half the bottom area of the furnace. A firebrick hearth is placed under the burner to catch any oil which may drop from it. A course of brick is also placed on each side, sufficiently high to protect the side sheets from excessive heat. A device corresponding to the ashpan of an ordinary locomotive is fitted with a damper, preferably at the back, to govern the admission of air. This is made as large as

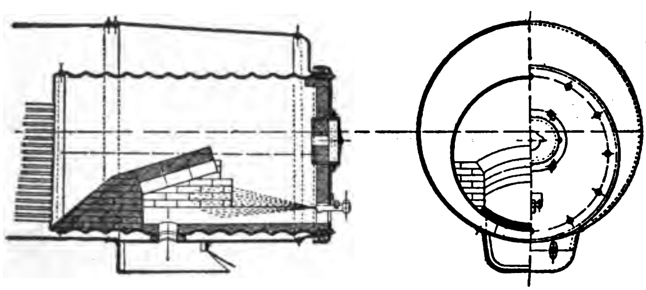

Figure 49. Oil-Burner in Vanderbilt Type of Firebox.

possible, with heavy frame, and is arranged to close perfectly air-tight so as to avoid loss of heat by circulation of cold air through the firebox and tubes when the oil-supply is cut off. The firedoor may be retained, provided its joints are perfectly air-tight; or a plate with a convenient sight-hole may be used instead. In either case the inner surface of the door is protected by firebrick to avoid liability of warping the metal.

In boilers with the Vanderbilt type of firebox, which is circular in cross-section, being rolled in the form of a large corrugated tube, the arrangement of the firebrick

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the fire-door through which sand is blown by steam with force, through the flues carrying with it the accretions of soot. This funnel is shown in detail in Fig. 51.

The oil reservoirs or tanks are made to apply to coal burner tank, one of which is made V-shaped to fit in coal space, in height to be made flush with top of tank. The other, or large tank, rectangular in shape, is made to fit on top of water tank, making perfect joint by connecting with small or V-shaped tank above mentioned.

These two, or pair of tanks, have a capacity of eight tons fuel oil. They are firmly anchored to water tank and tank frame. There is but one manhole for oil, and that is located on top of rectangular-shaped tank immediately over the joint or opening in small tank in coal space.

Each tank is fitted with automatic safety valve, with small chain or rope connection to the back of engine cab, with spring key which passes through upright rod of safety valve; in case of break-in-two between engine and tender this rope or chain pulls spring key out of rod, when safety valve will close automatically and stop feed or flow of oil from tank. An additional automatic or safety valve, also connected to engine by chain, is located in outlet oil pipe between tank and burner, which in case of break-in-two is automatically closed.

Heater pipes are placed in oil tank to reduce oil to proper consistency in cold weather.

There are a great variety of oil burners; with some it is necessary to have a separate heater box, others are made with heater box and burner combined.

In localities where heavy oil is used it is necessary to carry about five pounds pressure in oil tanks to facilitate

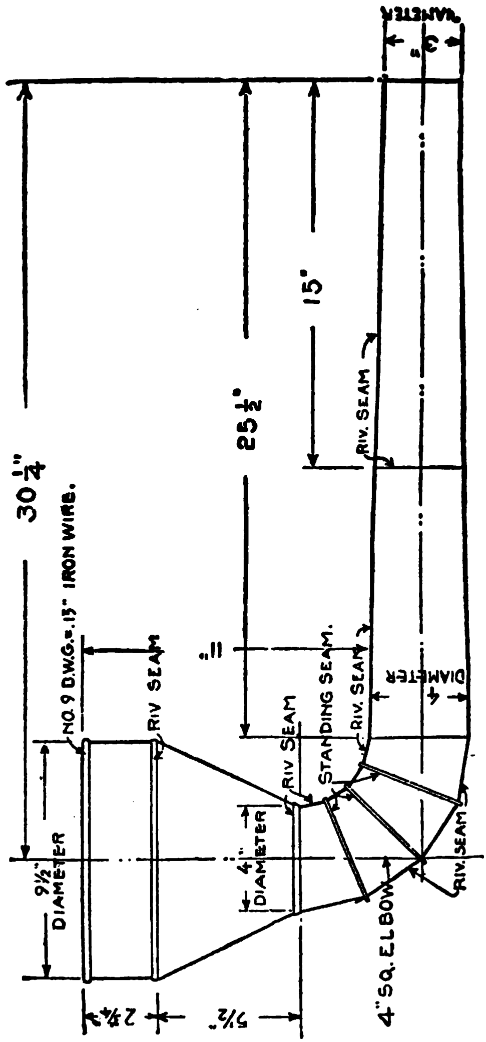

Figure 51. Sand Funnel Used in Cleaning Flues—Santa Fe

proper feed of oil. With light gravity and in warm weather pressure in tank is not necessary.

When new engines are furnished and built as oil burners, they are generally equipped with what is known in Southern California as Standard Combination Oil and Water Tank. These are constructed with oil tank submerged inside water tank.

Another authority says: To change from coal to oil fuel the grates are taken out and a cast-iron plate is placed 4 to 6 inches below the mud ring, extending over the entire space under the firebox. This plate has three openings for air to come up into the firebox, 9x15 inches, one of these air openings being in the middle of the firebox, one near the front end and one near the back end. This plate is protected from the heat of the fire above by a covering of firebrick. The ash pan and dampers are left the same as a coal burner. The sides of the firebox are also protected from the direct force of the intense heat by a firebrick wall about 5 inches thick, which comes up to the flues in front, up above the flare of the firebox on the sides and to the bottom of the door at the back. There is a brick arch extending across the firebox from side to side, reaching back well towards the door, just the same as in a soft coal burner. Some engines also have a narrow arch just under the door, which serves to keep the intense heat from the door ring.

The side walls of brick in the box do not last long, some of them not over three weeks. They can be patched by putting in new brick when holes are found in the old ones. Generally a whole new wall is put in at a time. With the oil burners the crown sheet lasts about as long as with coal, but the side sheets, even with the protection of the brick walls, give out at the flare of the box, near

the door and at the top of the brick walls on the sides. The staybolts behind the brick walls leak some, but it does not seem to affect the streaming; the water runs down the sheet into the pan if it is not all evaporated at once. When the flues of an oil burner begin to leak badly they soon stop up, and she dies in short order. In this they are different from coal burners.

The atomizer which separates the oil into a fine spray and blows it into the firebox is located just under the mud ring, pointing a little upward, so the stream of oil spray and steam would strike the opposite wall of the box a few inches above the bottom, if it was to fly clear across the box. Deep fireboxes have the atomizer at the back end of the box, while the shallow and long fireboxes have it located at the front end, pointed back. The shallow boxes have the same arrangement of side walls that the deep ones have, but the arch is put in differently; some of them have three small arches extending from side to side, but lapping over each other from front to back, so as to divide the current of flame and heat into several parts and thus distribute it over the long, shallow box more evenly. A good deal depends on the size and position of the arch, which has the same effect on the steaming of an oil burner that the diaphragm in the front end has on the draft of a coal burner. No air is admitted above the fire of the atomized oil.

The atomizers (one for each engine is used) are of brass, 12 inches long, 4½ inches wide from side to side and 2 inches thick from top to bottom, divided into two parts by a partition in the middle. Steam comes into the bottom part, heats the atomizer and issues through a slit 1-32 by 4 inches. The oil flows into the top part of the atomizer over the hot partition, and on running out of

the front end is caught by the steam issuing from the slit in the bottom part, and is sprayed into the fire, which when the engine is working, is a mass of flame, filling the firebox under the arch, and most of the time the whole box. If the supply of oil fed in is more than can be consumed in the box you will occasionally see little flashes of flame at the top of the stack.

The supply of steam and oil to the atomizer is regulated by the fireman from the cab, and handles for the steam and oil supply valves being placed where he can have his hands on them when on his seat box. He is located where he can see the gauge clearly, and as he sometimes pumps the engine with the left-hand injector, it has to be handy also.

Before the oil is fed into the atomizer it passes through a small heater made of brass, having a steam pipe through it; this same steam pipe also leads to a coil in the bottom of oil tank to warm the oil so it will flow easily. The oil on the Pacific Coast is not at all like the fuel oil we get from Indiana or the Lima field. Some of it has a generous portion of thick stuff like asphaltum in it, so it does not flow very easily; while other kinds are thin as water, and almost as clear.

The oil tank is located in the pit of the water tank, where we usually carry coal. In the tenders built especially for oil burners the oil tank is surrounded by the water. An air pipe leads from the main reservoir to the oil tank, with a reducing valve similar to the one used in the air signal line, but with a different spring box, so as to reduce the very high main reservoir pressures carried on the mountain engines down to 4 pounds, which is maintained in the oil tank, so the oil comes out freely. Self-closing valves are provided to shut off the flow of

oil in case the engine breaks loose from the tender, as in case of accident the oil flowing into the wreck would make a bad matter worse. The exhaust tip is about the same size as the engine would have if she was burning good coal. Some of the engines have no changes made in the front end except to take out the netting; others have a low nozzle and petticoat pipe put in instead of high nozzle and a diaphragm or apron. I was somewhat surprised at this, as it would seem that more air could be drawn into the box through three openings 9x15 inches in size than could come through a coal fire. Another surprise was the fact that oil burners make considerable smoke, although it was stated by some of the enginemen that if properly handled they would make no smoke; others said it was no harm if they made a little smoke at times. The oil makes a sort of sticky deposit in the flues, which soon coats them and interferes with the steaming. To cure this difficulty, the fireman sticks a long funnel through a hole in the firebox door made for that purpose, and gives the flues a dose of about four quarts of sand, which is drawn through the flues and scours them out. When this sand goes through, a black cloud comes out of the stack as thick as from any soft coal burner.

If this oil could be vaporized by heat as easily as it is atomized by steam, that is, changed into a gas instead of a spray, like gasoline is burned, it might be made smokeless; but the oil has a heavy residuum in it that cannot be vaporized very well. Then, the changing conditions under which the engine is worked interfere with perfect combustion. At one time, when working hard, a large stream of oil flows into the atomizer; when switching or running shut off a very little is used; so the fireman has

to open and close the oil supply valve with every change in the work of the engine. As there is no bed of live coal to hold back the air, just enough oil must be admitted and burned to heat all the air drawn in by the exhaust, for if this air struck the flues cold, as it would be sure to do if too small a supply of oil was burning, the cold air would soon set the flues leaking.

When these oil burners are in good order and properly handled it is astonishing how they will steam. When working on a hill with a full train and a steady pull for 21 miles, a ten-wheel Baldwin with 21x28-inch cylinders and 56-inch drivers would pick right up with both injectors on full, and these injectors large enough so one of them would ordinarily supply her. Of course, if not properly handled, oil burners will lag on their steam, but ordinarily they steam "like a house afire," as one of the firemen expressed it.

Firing one of them is not the soft snap some imagine because there is no coal to handle. The fireman must stay on his box, with his hand on the handle of the oil supply valve, which is like the handle of F-6 brake valve, and has very fine notches in the quadrant or ledge; he watches the gauge and the engineer and regulates the supply of oil to suit the work. When running shut off or switching at stations, it is a difficult matter to allow enough oil to go to the atomizer to keep the fire alive and yet not have too much.

There is a good deal of water in the oil, and they are so near the same specific gravity that the water comes through with the oil. When a charge of water comes through the fire goes out for an instant, but lights up again when the oil comes again. The end of the supply pipe for the oil is located a little way above the bottom

of the oil tank, so as to draw oil only, but the water comes in also. There is a drain pipe in the bottom of the oil tank, which can be opened at any time to drain off the water.

Several forms of atomizers are used, but most of them follow a general principle. One form has an air draft in with the oil, which helps the work of the atomizer, while another has no air openings in it.

At terminals there is no waiting to clean fires, arches or flues before the engine can go back. If the machinery is all right they take oil and water at the same time, and the engine is ready to go out, which is a saving when short of power. The oil is fed into the tender from elevated tanks just the same as water, and as quickly. Storage tanks are located along the road where needed, the same as coal chutes.

FIRING WITH LIQUID FUEL.

An impression prevails that on locomotives burning liquid fuel the fireman has nothing to do but open the valve admitting the oil and the burners will do the rest. The instructions issued by the Southern Pacific indicate that care and skill are requisite to burn liquid fuel properly. They are as follows:

"Before departure, see that oil tanks are full, oil heater in operation and oil heated to proper temperature as soon as possible; also that fire is burning, that no oil is dropping or lying in outer pan, and that no brick or other obstruction to the free passage of oil from the burner to front wall is lying on bottom of inner pan, and that sand buckets are full.

"Starting the Fire.—When firebox is below igniting point, which is a dull red, open dampers, start blower and atomizer medium hard, throw a piece of saturated oily waste, after lighting same, on to the bottom of inner pan; close and fasten firebox door, then turn on oil very light, and see if it ignites at once. If not, shut off oil at once, and see if waste is burning. When oil has ignited, reduce blower and atomizer to very light feed, also reduce oil flow until stack becomes almost clear. Starting the fire by the hot firebox, no waste is used.

"Temperature of Oil.—Kern River or thick oil to be heated to from 150 to 170 degrees, McKittrick or thin oil from 100 to 120 degrees; temperature to be taken from measuring rod suspended in forward tank. Vents on top of oil tanks to be kept open at all times, except when tanks are very full and oil is liable to splash out, they may be closed until oil is reduced from 5 to 7 inches in tanks, care being taken not to have any lights in hands when they are first opened after having been closed any length of time.

"Heating Oil by Direct Steam Application.—Put heater on strong until oil has reached the proper temperature, then close it off, give it another application. To keep the heater on light and constant might produce water enough in oil to become objectionable.

"Heating by the Coil in Tank.—Open cock on boiler head just sufficient to produce steam water at drain cock under tank. Superheater should be used constantly when weather is any way chilly. Keep drain cock to superheater open just sufficient to keep cylinder dry.

"Starting Train or Engine.—Engine should not be started until fireman is at firing valve. Remember that the care of firebox is an important as keeping up steam

or making time. Start engine carefully, so, if possible, not to slip engine. Open firing valve sufficiently to make sure that action of exhaust will not put out fire, but not enough to make great volumes of black smoke. Increase atomizer and oil gradually until full speed is attained, keeping just on verge of black smoke. When engine is hooked up, valves governing the admission of oil will be regulated according to required amount. It is well to use the blower about one-half turn while starting, as this will help to consume smoke between exhausts; also, keep engine hot.

"BLACK SMOKE.—Never make an excessively heavy smoke, as it only fills flues with soot, which is a great nonconductor of heat and produces no heat in itself. Strive to keep stack clear at all times, except when starting.

"SANDING FLUES.—Sand as frequently as required, according to amount of smoke made. If engine has to be smoked anyway hard, sand every 10 or 12 miles. But if stack is kept clear, sand every 30 to 50 miles. If any amount of switching is done at a station, sand immediately after leaving that station.

"HOW TO SAND.—Having attained a fair rate of speed, use about one quart of sand, close all dampers, put reverse lever near full stroke, open throttle wide, and allow sand to be drawn from funnel in a thin stream. Going into stations where stops are to be made great care must be exercised not to cut oil supply too low before throttle is closed.

"Any draft through firebox has a tendency to put fire out; the stronger the draft the stronger must be the oil supply. Consequently, there is great danger of fire being put entirely out before throttle is closed. When throttle

is closed and oil reduced, the atomizer must be cut down at once, so it will just keep oil from dropping on bottom of inner pan, otherwise the intense heat of the firebox will be blown down through air inlet burning bottoms of pans.

"Never allow fire to be put entirely out, except when giving up engine at end of run or when all hands are going away from engine. Then it must be put out. To put out fire, first close stop-cock under tank, allow oil to all be drawn from pipe and burner, then close firing valve, atomizer and all dampers. To blow obstruction from oil line, close firing valve, open cock between heater line and oil line, close heater line and turn cock on boiler head to heater line on full. This will blow all obstructions back in tank. This arrangement may be used to heat oil in tank in case of failure of coal heater. If any brick from walls or arches in firebox should fall in front of burner, it must be removed at once or pushed to the extreme front of firebox. Blue gas issuing from stack is indication that the fire is out or very nearly so. It is very objectionable and should be avoided if possible, especially so on passenger trains.

"Burners must be adjusted so that oil will strike about middle of front wall. If oil drags on bottom of pan, black smoke and poor steam will result. Burners are liable to clog up with sand that is in oil and by pieces of waste that are sucked up by air inlet. If trouble is found with it, the inner case or steam jet can be taken out in most cases without disturbing the outer case or adjustment of burner. In this manner any obstruction or defect may be readily located and remedied. The blower must never be used stronger than just sufficient to clear stack of black smoke Any more is only a waste

of fuel and a delay, as too strong a draft through firebox for the amount of oil admitted only absorbs heat and cools instead of heating firebox. At water tanks, where it is necessary to keep injector on all the time the train is standing, the oil supply must be left on a little heavy and blower on lightly. This will insure a full head of steam when ready to start. As the oil penetrates the arch brick and causes them to crumble away very fast, it is important to examine firebox frequently to know condition of it. As steam pressure increases on boiler, atomizer and blower will work stronger unless they are cut down. Be governed accordingly. Also remember that black smoke is very detrimental to steam generating, and that the more that is made, the more it becomes necessary to make."

To burn oil successfully no smoke must be made, as this lays a coat of soot on flues and sheets, which keeps the heat away. It may be asked why does soot accumulate on flues more with oil fuel than it does with coal? Simply because with coal you have cinders and particles of coal to keep it cut off, while with oil you have nothing passing through the flues but smoke, heat and gases. But sand is carried along for this purpose. If flues become sooted a quart or so is put into the firebox while the engine is working hard and is drawn through the flues at a high velocity, cutting the soot off to a great extent. When the throttle is closed and the fire being cut down great care must be exercised or fire will be put entirely out and this is what makes oil fuel so hard on fireboxes. Going into stations where stops are to be made, the sheets are expanded with the intense heat, and the careless fireman in cutting down his fire puts it entirely out. Take in consideration natural draft and add

to it velocity of moving train, and pump exhaust, all drawing cold air through firebox, cooling sheets and flues, and the consequences are sure to be disastrous to them. Of course, burning oil in locomotives is in its infancy, and there is room for a great deal of improvement, but considering the length of time we have been at it, it certainly is remarkable to see how those engines go up the hill with their heavy trains, with plenty steam and no smoke, no dust, no cinders and no sweating fireman.

GENERAL RULES FOR FIRING AND OPERATING AN "OIL-BURNER."

In firing up an oil burner locomotive in the round house, steam connection is made to the three way cocks on the smoke arch which acts as a blower and atomizer at the same time; then throw in the fire box, in front of the burner, a piece of greasy lighted waste; then start the oil to running slightly; then open the atomizer valve enough to atomize the oil which is flowing from the burner, and the oil will instantly ignite. The fire should be watched until steam begins to generate in the engine, when the round house steam can be cut off. Care should be taken not to turn on too much oil, for the explosion would drive the flame out of the fire box and might be the cause of injury to the operator. Care must also be taken to see that the fire does not go out when first started in a cold engine; if it does and is not noticed the oil will run into the pit and may take fire later on and explode and thus damage the engine. The fire must therefore be carefully watched until its burning is well assured after which there is little danger of this happening. Fire going out on an oil burning engine can be detected readily by observing the smoke coming out of the stack. If it is of a white, milky color, it indicates that the fire has gone out and that the oil is still running out into the pan; this smoke is caused by the heat of the brick in the bottom of the pan. That the fire has gone out can also be detected by the odor.

In firing up an oil burning locomotive where steam is

not available, wood may be used until ten or fifteen pounds of steam is generated in the boiler. The wood must be placed in the firebox with great care so as not to damage the brick work, and in using wood for this purpose care must be taken to avoid causing fires along the right of way or elsewhere.

It is very important that the proper amount of steam be admitted to the burner as an atomizer. It is also very important that the brick walls and arch of the locomotive be kept in perfect condition. Occasionally small pieces of brick will fall down and lodge in front of the burner, which will interfere with the engine steaming. All engines should be equipped with a pair of light tongs or a hook so that the fireman can remove these pieces of brick if necessary.

In oil burning engines it is necessary to occasionally use sand for cleaning the gum off the end of flues in the fire box. This sand is applied through an elbow-shaped funnel made for the purpose; the nozzle of the funnel is inserted through an aperture in the firedoor, and when sand is being applied by the fireman the engineer drops the lever in the corner notch and has his throttle wide open. This is very effective, and is only used three or four times in going over a long hard division.

In handling the oil burner on the road the engineers and firemen must work in harmony, i. e., when an engineer wishes to shut off the throttle he should notify the fireman in time so that the latter can close the oil valve in order to prevent waste of oil, the emission of black smoke and the "popping off" of the engine; and again, in starting up, the engineer should notify the fireman so that the oil valve may be opened before the

throttle, and the fire burning before any cold air is drawn into the firebox by the exhaust. In opening the valve the flow of oil should be gradually increased as the engineer increases the working of the engine. If this rule is carried out it will in a great measure prevent leaky flues, crown and stay bolts. Fireboxes can be easily damaged by over-firing.

In a coal burner if an engine drops back five or ten pounds pressure it takes some little time to regain it; in an oil burner the fire can be crowded so as to bring it up almost instantly and thereby overheat the plates and cause damage to the firebox. The practice should be to consume about as much time in bringing up steam on an oil burner as would be taken with a coal burner; too much care cannot be exercised in this particular. It is possible to melt the rivets off the inside of an oil burner firebox by over-firing.

In drifting down long grades, it is preferable to keep the fire burning a little rather than to shut it off entirely to prevent chilling of the firebox, adjusting the dampers to suit a light fire. The water can be carried in such a way approaching such points as will admit of working the injector occasionally to prevent popping off.

The use of the blower should be restricted all possible. It tends to make the firebox leak. If the blower is used at all it should be used very lightly, simply enough to cause a draught.

Some troubles have been encountered on account of waste getting into the oil tank; these are caused by carelessness on the part of Hostlers and Helpers in measuring the oil and wiping the measuring stick off with waste. Waste should therefore not be used for this purpose.

DONT'S.

Do not approach the man hole or vent holes of a tank closer than ten feet with a lighted torch or lantern.

Do not take a lighted torch or lantern to a man hole to ascertain the amount of oil in the tank; this should be done by the insertion of a stick or rod and the same carried to the light to ascertain the number of inches of oil shown on the stick or rod.

Do not, when making repairs to, or inspection of, an empty tank, place a lighted lamp or torch inside of the same before it has been thoroughly steamed and washed out, as gas will accumulate in an empty tank not so steamed and washed out, and explosion is liable. Employees are positively prohibited from entering tanks having contained crude oil, until the instructions to thoroughly steam and wash them out have been complied with.

Do not, in firing up, apply the atomizer and oil before putting in the lighted waste, as gas may accumulate in the firebox and thus cause an explosion.

In starting up or stopping, the engineer must always notify the fireman, as the starting or shutting off of fire must in all cases precede the opening and shutting off of the engine.

Before starting the fire raise back damper. See that the bottom of fire box in front of burner is free from brick or other obstructions that would interfere with free passage of oil from burner to front of firebox. Also see that there is no oil in the pan. Open blower strong enough to create necessary draught. Open atomizer valve long enough to blow water out of pipe. Then close valve and light a piece of oily waste and throw it

to the center of the firebox. Then turn on atomizer strong enough to carry oil to fire. Open valve slowly until the oil ignites, using only enough oil to generate steam without making black smoke. In firing up a cold engine the fire may go out. Watch it closely until the engine is hot. If at any time it should become necessary to fire up with wood, care should be taken that the brick work is not damaged.

Do not force the firing. Bring the firebox temperature up gradually. If pressure falls back five or ten pounds, restore the maximum pressure by gradual degrees. Forced firing will overheat the plates, burn off rivet heads, and cause leaks.

In sanding the flues to clean out the accumulations of soot and gum, drop the lever to half stroke and use full throttle for a few turns, while the sand is being injected.

Successful combustion of petroleum is smokeless.

An accurate combination of steam and oil in the atomizer and air admission is necessary to thorough combustion. To this end the steam and oil valves and dampers must be adjusted closely.

As all petrolem contains a greater or less per cent of volatile gases, which are given off at low temperatures, lighted torches, lamps or lanterns should never be taken in or near tanks containing oil.*

"While there are a few things to say against an oil-burning device on a locomotive, there are a great many things to say in its favor. It will reduce the life of flues and firebox about 25 per cent; while on the other hand it is perfectly free from starting fires on the right-of-way or setting fire to equipment. The cost of handling fuel

*The foregoing rules are those in force on the Santa Fe system.

is at least 75 per cent cheaper than that of coal. It does away with clinkering of engines at terminals and on the road; reduces the time consumed in turning power; does not have any cinders to take care of. If the oil crane and water tank are spotted at places so that the oil and water can be taken at the same time, there is no reason why an engine cannot be turned in from 20 to 25 minutes. There is little or nothing to get wrong with an oil burner, so far as the oil-burning apparatus is concerned; burner may stop up with sediment or burst from heat, but these are rare occurrences.

PUTTING OUT FIRES.

First shut off the oil valve on tank. Allow oil to be burned from pipe to burner. Then close firing valve, atomizer and dampers. It is important that damper should be closed to prevent passage of cold air through fire box and tubes, when they are heated after the fire has been extinguished.

PREVENTION OF SMOKE.

Black smoke should be at all times avoided and if in evidence shows faulty construction of brick work or improper methods of handling. The soot formed by smoke is a non-conductor and will make an oil burning engine fail in steam quicker than any other cause. An accurate combination of oil and steam in the atomizer, with the proper admission of air, is necessary to thorough combustion. To prevent smoke in starting and stopping, engineers should always notify the fireman when they are going to open or close the throttle.

CAUSES OF FAILURES AND HOW TO PREVENT THEM IN OIL-BURNERS.

First.—Smoke which stops up the flues with soot.

The firing valve should be opened gradually when engine is first started. Care should be taken to maintain the temperature of the firebox as nearly uniform as possible. The supply of oil should be gradually increased as the engine increases in speed in accordance with the requirements of service. Do not force the firing. If the pressure falls back five or ten pounds, restore the maximum pressure by degrees. Forced firing will fill the flues with soot, over-heat the sheets, burn off rivet heads and cause the boiler to leak.

Second.—Improper sanding.

The engine should be well sanded on going from the round-house to train, where practicable; again in pulling out; and several times the first mile or two. This is very important as engines are more liable to be smoked up in starting the fire and around terminals than after starting. Keep on sanding as long as quantities of black smoke follow the act of sanding. If the supply of sand runs short you can take it from the main sand-box or get it from the cinder pot in front end and use it over again. Always hold the funnel in a position to carry the sand over instead of under the arch.

Third.—Insufficient flow of oil to burner.

Burners are liable to clog up with sand that is in the oil, or by pieces of waste sucked up by the air inlet. A partial or complete stoppage of oil pipe or burner may be overcome by using the blow-back valve. To use this, open tank valve, closing firing valve, and open cock over super-heater. This will blow steam back through oil

supply pipe. Then close tank valve and open firing valve. This will blow steam through oil pipe to burner. If the obstruction is not removed by doing this the pipes will have to be disconnected or atomizer tube removed. Care should be taken to see that this blow-back valve is closed except when used for blowing out pipe or burner. If left open or leaking it will prevent free passage of oil to burner, thereby causing a series of explosions. Sometimes a partial obstruction may be overcome by closing the air intake valve. This creates a partial vacuum in the burner. If oil flows out of the intake pipe it is evident that the obstruction is in the rubber hose from pipe to burner. This becomes burned from the heat of the boiler and closes up. Also the same with the hose from the supply tank to engine as the action of the oil on the rubber has a tendency to soften it and causes same to close up.

Fourth.—Water in oil.

In case the fire goes out from unknown causes you should ascertain whether there is water in the oil, by opening the drain cock. Water accumulates in oil tanks sometimes by improper handling of heater. Opening it only a small amount and leaving it on continually, is bad practice. Put it on strong, heat the oil and shut it off. This should be done as much as possible when standing.

Fifth.—Fallen brick on bottom of firebox or striking an obstruction caused by an accumulation of asphalt.

An engine will not steam well and will cause an excessive amount of black smoke if the fire drags on bottom or strikes a fallen brick. Round-house men should inspect and clean pan under burner thoroughly. Crews should inspect and take them out or push them forward and remove the accumulation of asphalt and sand. The best time to do this is when the fire has just been par-

tially shut off while at a station. Too much attention cannot be given to this matter.

Sixth—Partial or complete closing of atomizer tube in burner.

If the full opening of the atomizer valve will not remove obstruction the tube must be taken out of the burner. In most engines this can be done in from five to ten minutes.

Seventh.—Slipping or working the engine hard with fire out.

Slipping or working the engine hard with the fire out or starting before the fire is lighted, will cause the flues to leak almost immediately. Great care should be taken to prevent this. Should it become necessary to do any work inside of the oil tanks after they are empty, first fill the tank with water. Put in a few pounds of caustic soda. Then turn on steam through the heater pipe, until water boils over the manhole. Petroleum contains a greater or less per cent of volatile gases which are given off at a low temperature; therefore under no circumstances should lighted torches, lamps or lanterns be taken into tanks or near the openings that have contained crude oil until they have been thoroughly cleansed.

A FEW POINTERS THAT SHOULD BE REMEMBERED.

Do not leave the fire door unfastened when starting fire for if too much oil is turned on an explosion may occur which will drive the flames out of the door and might injure any one in the cab.

Do not use the blower at any time stronger than is necessary to clear the stack of black smoke as it is a waste of fuel, makes an unnecessary noise and if the fire

is burning lightly will cause the flues to leak. Do not start the engine without having the firing valve opened sufficiently to insure a good fire so that the cold air may not be drawn through the flues by the exhaust. Do not go nearer than ten feet to a manhole or venthole in a tank with a lighted torch or lantern. To ascertain the amount of oil in the tank use the rod made for that purpose, carrying it to the light to find the number of inches or gallons in the tank, unless you have an incandescent globe to carry with you. Do not allow the air supply cut off from fire by asphalt, sand or pieces of fallen brick accumulating in the pan; hoe it out. Do not start fire without first lighting a piece of oily waste. If in backing down to train or switch engines backing down in yard the fire should go out, shut off the oil and start fire by lighting a piece of waste, for if you do not do this you are liable to cause an explosion.

CATECHISM ON OIL BURNING LOCOMOTIVES.

What are the fireman's duties on arrival at engine house previous to going out with an oil-burning engine?

It is his duty to see that the heater is adjusted and the oil is heated sufficiently and that the oil is in condition to flow freely to the burner.

How warm should oil be at all times in tank?

The best results are obtained when the oil is heated to such a temperature that the hand can be held on the tank, or to about 110 degrees, Fahrenheit.

If the oil is too warm what happens?

Some of the qualities of the oil are lost by the constant boiling and the burner does not work so well and will make it more difficult to operate.

What tools are necessary for firing purposes on an oil-burning engine?

The necessary tools allowed by the railroad for which you are working.

What is liable to happen if heater valve is open too much?

It is very apt to burst a hose.

What should be done on approaching oil supply stations, where additional supply of fuel oil is to be taken?

See that there are no lamps or lights on the tender when you stop.

What care must be exercised in the use of lamps, torches or lanterns about oil tanks, whether hot or cold. Why?

Do not carry, or permit any one to carry, oil lamps or oil torches within a distance of ten feet of tank opening.

How should depth of oil in tank be measured without taking a light to manhole?

By the gauge.

What precaution must be taken before entering tanks that have been used for oil, to clean or make repairs?

You should not enter tanks until they have been thoroughly cleansed.

How should the fire be lighted in oil-burning engines?

See that the boiler is properly filled by trying the gauge cocks when the fire is lighted in the round house. Steam connection can be made to the three way cock on the smoke arch which will act as blower and atomizer. If you have steam on engine, 20 or 30 pounds, it can be operated with its own blower. See that the front of the firebox is free from carbon or anything that would obstruct it from burning; it must have free passage so oil can get to burner. Open the front damper, put on the blower strong enough to make the necessary draft, open the atomizer valve long enough to blow out any water which might be in steam pipe or burner; next close the valve and throw a bunch of lighted old waste in front of the burner, then open the atomizer sufficiently to carry oil to the waste and open the regulator slowly until the oil is known to be ignited—this you can see through the firebox door.

Should the fire go out and it is desired to re-kindle it while bricks are hot, is it safe to depend on the hot bricks igniting the oil without the use of lighted waste?

No, always use waste in re-kindling the fire as the bricks are not very reliable and apt to do damage from explosive gases formed.

What is termed an atomizer, and what duties does it perform?

The atomizers are made of brass, 12 inches long, 4½ inches wide and 2 inches thick from top to bottom, divided into two parts by a partition in the middle; they separate the oil into a fine spray and blow it into the firebox. The atomizer is located just under the mud ring, pointed a little upward, so the stream of oil and spray of steam will strike the opposite wall a few inches above the bottom if it were to pass clear across the box. Deep fireboxes have the atomizer at the back end of the box, while the shallow and long fireboxes have it located at the front end, pointed back.

In starting up or shutting off throttle of an engine, how should the fireman regulate the fire, in advance or after the action of the engineer?

In advance of the engineer's action.

Is it, therefore, necessary that the fireman and engineer on an oil-burning engine work in perfect harmony, and advise each other of intended action at every change of conditions?

Yes, they should work in harmony with one another and while the fireman should watch every move the engineer makes it is also the duty of the engineer to advise the firemen of every change of the throttle so that he can operate his valves according therewith and thus save fuel.

What is the effect on a firebox of forcing the fire on an oil-burning locomotive?

It will cause the flues to leak. Always keep an even temperature in the firebox.

Is a careful regulation of steam and oil valves and dampers necessary to obtain the most economical results?

Yes, the firing valve should be opened sufficiently to make it certain that enough oil is being fed to produce a

good fire, but not enough to cause a great volume of black smoke.

How can you judge whether the combustion is good or bad, so that the valve may be regulated accordingly?

By noting the smoke emitted from the stack.

How should flues be cleaned from soot when running, and about how often is it necessary?

The flues should be cleaned out after leaving terminals, or after an engine has been standing for some time. The use of the sand, frequently and in small quantities, is recommended.

Is the injudicious use of the blower particularly injurious to an oil-burning engine?

Yes, the frequent use of the blower is injurious to a firebox and the cold air drawn in through the flues will cause them to leak.

Is the blower more injurious when a light smoke is emitted from the stack, or when a black smoke is emitted?

It is more injurious when a light smoke is emitted from the stack.

In drifting down long grades should fire be shut off entirely or burned lightly? Why?

The fire should be burning lightly, yet it should not be permitted to get too low, allowing the firebox to lose its temperature and thus causing the flues to leak.

How should the fire be handled when switching?

It should be used the same as when running.

Would not some fuel be wasted in this manner?

Very little will be wasted if the fireman watches closely.

How should fire be handled leaving stations?

It should be burning brightly and sufficiently strong to keep from going out.

Which is desirable—to use as much or as little steam-jet atomizer as possible?

Use as little atomizer as possible at all times.

What is the result of too little steam atomizer, when standing at stations, or engine working light?

It is very apt to allow the fire to go out.

If too much steam atomizer is used with little fire?

It will use too much steam and reduce the temperature of the firebox.

When the fire kicks and smokes what should be done?

The blower should be put on and the dampers closed.

How should the dampers be used on an oil-burning engine?

They should be closed when drifting to prevent cold air being drawn in, causing flues and stay-bolts to leak.

About how much smoke do you consider an oil-burning engine should make under adverse conditions, when engine is steaming well, but is being crowded by engineer to make up time?

No more than when an engine is working ordinarily.

What color is most desirable at peep holes in fire-door?

A bright, ruddy color.

What will produce a ruddy color?

By feeding only the amount of oil that is properly burned and watching the regulating valves closely.

How does water in oil affect the fire?

It affects the flame and requires more oil than otherwise.

COMBUSTION.

Next to wages, the fuel bill is the largest single item in the cost of conducting railway transportation. Recognition of this fact by railway managements has long been evident in their efforts toward its reduction through a consistent policy of giving trial to practically every feature of locomotive design which gives promise of enabling increased economy of operation. Both money and time have been freely given to exhaustive trial of all ideas in boiler proportions, front end arrangements, compounding, superheating, etc., as well as to investments in fuel handling plants seeking to cheapen the cost of placing the fuel on the tender.

Is it unreasonable then for the managements to expect the co-operation of the engine crews in obtaining the results sought for by all this investment, viz: a reduction in the fuel cost of conducting transportation? For, since the actual generation and utilization of the steam is entirely in the hands of the engine crew, the greatest factor in the fuel bill is of necessity, entirely a matter of engine crew skill and judgment, and our managements are certainly entitled to much credit for their policy of encouraging rather than insisting upon reasonably economical methods of firing and running.

Since one must know the reason for doing things in order to be sure of getting satisfactory results, it has been thought of interest to gather certain scientific facts relating to fuels and the combustion process and show their relations to the operation of locomotive firing. No

one appreciates better than the author the seemingly remote relation of theoretical expositions to the work in prospect, when one crawls up the left side of a power-house-on-wheels, attached to a little less than a mile of cars, at three o'clock of a winter's morning. Yet he remembers an instance where such relations were most distinctly brought out in a case where life was made miserable for a succession of firemen who could not keep hot a class of engines which had the name of being good steamers on the division from which they had been procured. This continued until the mechanical engineer came down and recalled the fact that on the original division the coal was of about 14,000 B. T. U. quality, which gave an evaporation of about 8 lbs. of water per pound of coal. Also that on the hard part of the runs the engines had required about 2.5 tons of this coal per hour, which, on the 30 sq. ft. of grate area of these engines, meant a combustion rate of 167 lbs of coal per sq. ft. of grate area. On the present division the coal was of only about 11,000 B. T. U. quality, which would give an evaporation of only 6.3 lbs. of water per lb. of coal and hence it would require the burning of 6,350 lbs. of coal per hour, at a combustion rate of 202 lbs. of coal per sq. ft. of grate area per hour—a practical impossibility.

It will be the aim of these articles to show such relations rather than to merely set down bare theoretical facts, and because of this aim the author takes the liberty of abandoning the usual methodical progress in things, preferring to show the applications in the most apt places.

As wood, coal and petroleum are the only locomotive fuels used in this country, we will not concern ourselves with other fuels. And since wood has practically passed

from the field, it may be well to dismiss it with the remark that one pound of coal is equal in heat value to about 2¼ pounds of dry wood of any species. As this leaves but coal and petroleum, it may be well to give the geological statement on the origin of these fuels, as follows:

At one period of the earth's development, known as the carboniferous age, the atmosphere carried a far greater amount of carbonic acid than at present. This carbonic acid is the food of plant life and, in consequence of attendant favoring climatic conditions, the vegetation was luxuriant in the extreme. This period continued until the atmosphere became poor in carbonic acid. The result was immense beds of decomposed vegetation (peat) which, under ensuing geological changes, became submerged and overlaid to a greater or less depth with later formations of the earth's present surface. According to the pressure exerted by these superimposed weights these peat beds were converted through compression into what we now recognize, in order, as brown lignite, black lignite, low-grade bituminous, high-grade bituminous, semi-bituminous and semi-anthracite coals. In certain localities, to this element of pressure there was an added element of igneous (viz.: from the interior of the earth) heat, which subjected the peat bed to a process of distillation which set free the volatile constituents (hydro-carbons) and left solely the fixed carbon of anthracite coal. The volatile constituents, in the form of gas or oil, thus set free were driven into natural reservoirs of the earth, which are now tapped as "gas" or "oil wells."

Because these beds of coal are discovered today in various stages of the completeness of this evolution, it

is obvious that there can be no sharp demarkations drawn between these classifications. The chemical constitution of coal comprises carbon, hydrogen, oxygen, nitrogen, sulphur and ash (or earthy matter). After an extended investigation of the coals of this country, the coal testing section of the United States Geological Survey has adopted a classification whereby a coal is designated by its percentage of carbon, divided by its percentage of hydrogen, as follows:

Table I.

	Carbon-hydrogen ratio
Lignite	9.3 to 11.22
Bituminous—four grades	11.2 to 12.5
	12.5 to 14.4
	14.4 to 17.0
	17.0 to 20.0
Semi-bituminous	20 to 23
Semi-anthracite	23 to 26
Anthracite—two grades	26 to 30
	30 and above

That is to say, that a coal analyzing, say, carbon 78.16 per cent, hydrogen 3.85 per cent, would ($78.16 \div 7.37 = 10.6$) fall under the lignite classification. Or, one analyzing 78.43 per cent of carbon and 3.66 per cent of hydrogen would, ($78.43 \div 3.66 = 21.4$) fall under the semi-bituminous classification.

The indications of the classification referred to in the previous section of this series, appearing on page 371 of the November, 1906, issue of Railway Master Mechanic, are shown in the table below and are typical examples compiled from the tests mentioned.

As a lignite represents the most incomplete evolution

of coal, occupying as it does a stage between peat and bituminous coal, its physical structure generally retains more or less trace of its plant life origin. It may be either brown or black in color and breaks unevenly with a dull lustre. It crumbles easily and on exposure to the weather absorbs much moisture.

As its total percentage of carbon is relatively low, and its percentage of hydrogen is also less than in most of the other classes of coal, its heat value is low (see table II) and a great quantity of it must be burned to provide the same quantity of steam than where bituminous coal is used. For instance the Texas lignite noted in the table has a heat value of 10,990 B. T. U., while the Indian Territory bituminous has 14,624 B. T. U. Hence the lignite is but 10,990÷14,624=75 per cent as efficient, or in other words, it would be necessary to burn 1¼ tons of this lignite to produce the amount of steam which one ton of this Indian Territory bituminous coal would generate. Or, taking 5,000 lbs. (2.5 tons) of coal per hour as the maximum capacity of a fireman in continuous freight service and 8 lbs. of water to 220 lbs. pressure steam per lb. of the Indian Territory coal per hour as the evaporation obtainable with this grade of coal, we will have as the maximum which one fireman can produce with the Indian Territory coal 5,000×8=40,000 lbs. of water per hour. But with the Texas lignite, since 75 per cent. of the 8 is 6, 5,000×=30,000 lbs. of water per hour. Or, since at 220 lbs. pressure steam has a volume of 1.94, we have 40,000×1.94=77,600 cu. ft. of steam per hour, with the Indian Territory coal; and 30,000×1.94=58,200 cu. ft. of steam per hour with the Texas lignite.

Assuming a cylinder stroke of 32 ins. and a cut off of

75 per cent for maximum working at a speed of 8 miles per hour with a 56 ins. driving wheel, we may then determine as the maximum sizes of simple freight locomotives which these two fuels will enable to be operated, as follows:

The diameter of the cylinders for the locomotive using the Indian Territory coal will be

$$\sqrt{\frac{\dfrac{77{,}600 \text{ cu. ft. of steam}}{.7854\times 32 \text{ ins.}\times 3 \text{ (for } 75\%)\times 5280 \text{ ft.}\times 12 \text{ ins.}\times 10 \text{ m.p.h.}}}{1728\times 3.1416\times 56}} = 22.23 \text{ ins.}$$

while with the lignite we can only supply cylinders

$$\sqrt{\frac{\dfrac{58{,}200}{.7854\times 32\times 3\times 5280\times 12\times 10}}{1728\times 3.1416\times 56}} = 19.25 \text{ ins. in diameter}$$

This would mean we could only secure

$$\frac{19.25^2\times 32\times (80\% \text{ of } 220)}{56} = 37{,}473 \text{ lbs. of}$$

tractive effort from the use of the Texas lignite, while with the Indian Territory bituminous we could secure

$$\frac{22.23^2\times 32\times (80\% \text{ of } 220)}{56} = 49{,}735 \text{ lbs. of}$$

tractive efforts.

Or, figuring the tractive effort as utilizing 22.5 per cent of the weight on drivers, we could operate a locomotive weighing $49{,}735 \div 22.5 = 221{,}047$ lbs. on drivers with this grade of bituminous coal, whereas one of only $37{,}473 \div 22.5 = 166{,}547$ lbs. on drivers could be operated with the lignite.

		Air-dried samples		Prox. Analysis (Samples direct from cars)					Ultimate Analysis (Samples thoroughly dried)							Earthy Matter in Ash and Refuse (per cent)
		Carbon-Hydrogen Ratio	British Thermal Units	Fixed Carbon	Volatile Matter	Moisture	Ash	Fixed Carbon (percent of combustible)	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Carbon (percent of combustible)	
Pennsylvania Anthracite.... (Spadra)		26.7	14,906	55.00	27.62	3.00	14.38	66.57	74.00	4.42	4.44	1.08	1.16	14.81	86.97	63.88
Arkansas Semi-Bituminous.. (Pocohontas)		20.7	15,270	73.68	12.54	2.22	11.56	85.46	78.43	3.66	2.27	1.42	2.45	11.77	98.80	57.05
West Virginia Bituminous..: (New River)	First Grade	19.6	15,786	68.36	16.31	4.85	10.48	80.74	80.34	4.00	3.11	1.05	.49	11.01	90.28	73.87
West Virginia Bituminous... (Upper Freeport)		17.8	15,743	70.03	22.38	2.14	5.45	75.78	83.71	4.64	3.67	1.70	.71	5.57	88.65	59.68
West Virginia Bituminous.. (Pittsburg)	Second Grade	16.1	15,440	59.84	27.04	2.53	9.90	68 40	77.42	4.69	5.18	1.48	.98	10.25	86.26	71.76
West Virginia Bituminous... (Hartshorne)		14.4	15,048	48.80	39.23	2.01	9.96	55.44	74.36	4.93	6.40	1 37	2.77	10.17	82.78	69.06
Indian Territory Bituminous. (Morgan)	Third Grade	14.3	14,624	50.31	32.61	3.71	9.77	58.15	74 00	4.97	7.66	1.78	1.44	10.15	82 36	79.04
Missouri Bituminous........ (Marion)		12.6	14,276	42.11	40.10	12.24	5.55	51.22	76.05	5.42	5.75	.79	5.67	6.82	81.18	73.83
Iowa Bituminous........... (Bevier)	Fourth Grade	12.4	13,471	33.73	35.35	14.88	16.04	48.83	62.04	4.49	7.59	1.50	5.56	18.82	76.42	81.93
Missouri Bituminous........ (Gallup)		11.8	12,638	39.76	31.77	11.57	16.90	55.59	62 38	4.37	7.84	1.10	6.20	19.11	77.12	80.17
New Mexico Lignite........ (Houston)		11.2	12,309	41.57	37.85	11.90	8.68	52.34	70.77	4.97	12.63	1.15	.63	9.85	78.50	57.02
Texas Lignite..............		9.4	10,990	29.44	31.42	23.27	15.87	48.37	62 85	3.94	10.73	1.10	.70	20.68	79.28	62.87

Naturally, since lignite has suffered the least change from peat stage through the factors of age, compression and heat, it is the lightest of the coals and its use in locomotives requires a different method of handling from the more advanced coals. Being light, it is easily dragged from its position on the grates, hence a softer draft is required than is permissible with bituminous coal; in other words a larger nozzle tip is used with the lignite. This fact of lightness also leads to a fire throwing effect greatly resembling wood, so that a 4 by 4 or even a 5 by 5 netting is generally used —in fact the diamond stack either with a short front end without netting or a long front end with netting is found essential as in burning wood. Lignite coats the tube sheet after the manner of wood, where the slightest tube leakage is present. By reason of the fine netting required the amount of opening in the grate intersticing becomes highly important, though this cannot be made too great on account of the light fuel falling through. A 35 per cent intersticing is generally practiced, with a rocking type of grate throughout (dump grate not required) though the fire should be disturbed as little as possible by grate shaking.

A deep ash pan is preferably used because of the considerable amount of ash falling into it with most grades; and a large amount of air openings protected by netting is imperative. In firing, a good depth (body) of fire is first built up and then kept at this depth through firing on the one or two shovel plan. There is sometimes a considerable tendency for the fire to "kick back" through the door, which must be watched. Some lignites have very little clinker, while others contain a large percentage.

As the deposits of bituminous coal are very widely distributed and the general run of it is well adapted to the purpose, this is the coal most generally used in locomotives. In color it varies from a dark brown to a deep black. In physical structure its lower grades (in its evolution from peat) are generally found less compact and to crumble rather than fracture, but as the grades are found more advanced toward the semi-bituminous or semi-anthracite stage, the structure is more compact and it fractures cleanly with a bright lustre.

As observed in Table II., the United States Geological Survey classifies the bituminous coals into four grades, of which the characteristics of typical examples in the upper and lower limits of each grade are set forth in the table.

Bituminous coals in general may be said to carry as much and generally more fixed carbon than the lignites, but less than these classes known as semi-bituminous, semi-anthracite, or anthracite proper. But the distinguishing characteristics of a bituminous coal is its high percentage of volatile combustible matter, which is present to a less extent in lignites and is extremely low in anthracites. When the bituminous coal is ignited, this volatile combustible matter is set free and burns with a long flame which terminates in invisibility under proper conditions of combustion, but under improper conditions this flame terminates in smoke.

Owing to the wide range of the individual characteristics of bituminous coals, both the arrangements for burning and the methods of firing must of necessity vary considerably. For instance, with the West Vir-

ginia Pocahontas coal in Table II, a larger extent of grate opening can be used, a lesser area of grate surface is necessary, a larger nozzle tip and a larger mesh of netting can be used and a generally smaller boiler will be necessary than with the, say, Iowa Marion coal further down in the table.

Differences in firing methods are permissible or compelled by the lightness or fineness of the coal, or by variations in the amounts of slate, iron, or other clinkering substances which are encountered in the coal furnished. For instance, the author remembers noting on the Bessemer & Lake Erie, an excellent grade of coal received directly on the tenders from the mine's mouth, used in heavy consolidation locomotives with long, narrow, "above-the-frames" fireboxes. The firing practice was to merely load in several scoops of coal just in front of the door. At the next firing interval, the hoe was thrown into the now-coked mass and all of it spread out up ahead. At the next firing interval, fresh coal was again piled up in front of the door for coking. This method of firing gave excellent results, with much less physical exertion than was involved in the usual method of distributing with the scoop; yet it was only possible because of the practically total absence of clinkering material and the coking nature of the coal. In firing, as in everything else, judgment is essential and the best method of handling a coal which is new to the man or to the division, can only be found after some experiment both with the coal and with the particular locomotive. With a careful noting of conditions and behavior, however, a good fireman will grasp these requisites within the space of a few fires.

We still hear the "two-shovel" method of firing, or the Bates door practice, held up as the ideal. While, of course, light firing at short intervals is the proper way to secure the best results, still these criterions of what constitutes light firing were fixed in the days of small power and light trains. In these days of heavy power and tonnage freight trains, or heavy, high-speed passenger trains the intervals between firing are so short as to almost preclude any other method than that of standing on the deck and firing continuously on the major portions of the run.

As a matter of fact, light firing with either light or heavy power does not mean so much that the fireman should use two scoops at short intervals, as that he should *not* use twelve scoops at ill judged intervals, that he should *not* fire heavily in light parts of the run, that he should know his division and *not* put in a heavy fire just when he knows the engine is to be shut off, and that he should *not* seek to impress the natives around stations by opening up a gas factory. In short, light firing means stinting the fire as much as possible all over the road and instead of seeing how much coal one can put into the firebox, to cheat it at every opportunity.

While the theoretical reasons for which it is more desirable to fire small quantities at short intervals rather than larger quantities at longer intervals, are set forth in the following chapter, it may be said in substance at this point that with light firing the glowing bed of fire necessary for perfect combustion is not cooled off so much with a thin layer of coal as it is with a thick layer, in other words heavy firing lowers the temperature of the fire. Again, where a large quantity of coal is thrown

on the fire, the air essential to its combustion cannot immediately get to this fresh coal in quantities sufficient to provide for perfect combustion. From both these causes, the fire is not so hot as it would be with perfect combustion and a more or less portion of the combustible material in the coal is not transformed into heat, but passes out of the stack in smoke, indicating the imperfect part of the combustion process of that particular "fire" put in.

Anthracite coal, being the final evolution of coal in having had the volatile constituents practically all driven off, is composed principally of fixed carbon and hence gives out little flame or combustible gases during the process of burning. Because of this, the heat of the fire is developed more in the immediate vicinity of the grates, so much so in fact, that it is usual to replace the common arrangement of grates with a design which embraces a number of water tubes in the grate area.

As but little gas is formed while burning anthracite, little smoke is produced, and fairly good combustion can be effected by passing the air through the grates alone. With a very thick fire, however, sufficient air cannot be forced through the grates and coal to admit of complete combustion and, therefore, carbonic oxide in place of carbon dioxide will be formed with a great loss of heat, if the air is not admitted above the fire. When carbon and oxygen unite to form carbon oxide, only 4,500 units of heat are generated, whereas, if they combine to form carbon dioxide (complete combustion) 14,500 heat units will be produced, and 10,000 heat units gained simply by securing complete combustion. To effect this and to save the 10,000 heat units, sufficient air must at all times be admitted to complete the combustion.

Although the heat units of anthracite and the high grade bituminous coals run about the same in amount, yet anthracite coal burns more slowly than the other coals. Therefore the amount of heat given off by anthracite coal within a given time is not so great in amount as would be true of bituminous coal. Hence, to obtain the amount of heat required by a locomotive within a given time, more anthracite coal must be kept in the process of burning. In other words we must use a larger grate area with anthracite than with bituminous coal. Anthracite is broken like bituminous coal and, therefore, must be fired as it is furnished. The thickness of the fire will depend upon the size of the coal to be used. It will be impossible to keep up steam with a thin fire composed of large sized coal, for the reason that large quantities of air would rush through the openings between the lumps, causing all the losses so often mentioned as due to too much air. In fact, to properly fire anthracite coal so as to give the required steam pressure with complete combustion as much skill is required as with bituminous coal.

Petroleum or fuel oil, as already explained, is the result of a distillation of lignite of bituminous coal under great pressure. It is a thick, very dark liquid, having an occasional greenish tinge. It is a hydro-carbon liquid, or rather is composed of a large category of liquid hydro-carbons of various chemical constituents. An average sample presents the following ultimate analysis:

Carbon	84 per cent
Hydrogen	14 per cent
Oxygen	2 per cent

In British thermal units this sample scales 20,845.

Some calorimeter tests on samples of California oil resulted as follows:

Heat Value			Per Cent Sulphur.	Per Cent Moisture	Per Cent Silt.	Specific Gravity.
Calories per Gram.		B. T. U. per lb. Average.				
Actual Results.	Average.					
9378 9405	9391.5	16904.7	.85 .84	8.71	.032	.9637
10314 10329	10321.5	18578.7	.... .96	.42	.010	.9407
10247 10229	10238.0	18428.4	.96 .99	1.06	.031	.9417
9407 9433	9420.0	16956.0	... .84	8.82	.024	.9629
10252 10280	10266.0	18478.8	.70 .77	1.06	.010	.9430
10316 10314	10315.0	18567.0	... 1.01	.74	.024	.9410
9929 9946	9937.5	17887.5	.93 .98	4.62	.048	.9529
9871 9897	9884.0	17791.2	.... .98	4.93	.054	.9530

In the southwest, where most of the fuel oil is used in locomotives it is generally taken that about four barrels of fuel oil is equal to one ton of coal. Some tests made on the Southern Pacific in 1901 resulted in the finding that 170 gallons of fuel oil were equal to one ton of coal. This would appear to be reasonable, for from the above table the oil will weigh roughly 7.9 lbs. per gallon which, at 42 gallons to a barrel would give 331.8 lbs. of oil per barrel. Taking 18,000 B. T. U.'s as the average heat value we have each barrel of oil providing 5,972,400 B. T. U.'s or 24 million heat units in four barrels of 168 total gallons. The coal referred to probably ran about 13,000 B. T. U.'s per lb., or, also 24 million B. T. U.'s per ton, so that as far as the relative cost of fuel is concerned, oil of this quantity at 50

cents a barrel would equal this grade of coal at $2.00 per ton. For railway use, however, there are other considerations involved. While requiring less physical exertion, its use demands greater attention from the fireman and a careless fireman cannot only cause much more discomfort through the production of black smoke but he can damage a firebox to an extent impossible with coal. On the other hand the oil can be transported and handled much more conveniently and cheaply than coal and the delay and general cost both on the road and at the roundhouse due to dirty, clinkered fires, fire cleaning and cinder handling, is entirely avoided. The specific methods of firing this fuel will be taken up later.

Most substances can, by proper methods, be separated into two or more substances of a simpler nature, and these can again be separated into still simpler means, which cannot be further separated or decomposed by any means known. Such substances as cannot be decomposed into simpler ones are called elements. Although there are thousands of different substances, they are really made up of a comparatively small number of elements. There are but sixty or seventy elements that are known, and a large number of these are rarely met with. The following is a list of a few of the more common elements, the letter or letters after each name being the "symbol" of the element; Oxygen, O; Hydrogen, H; Nitrogen, N; Carbon, C; Sulphur, S; Tin, Sn. Copper, Cu; Lead, Pb; Zinc, Zn; Silver, Ag; Gold, Au; Mercury, Hg; Nickel, Ni; Aluminum, Al; Platinum, Pt. The elements, oxygen, hydrogen and nitrogen, are gases at ordinary temperatures. When two or more elementary substances combine chemically, they form what is known as a compound substance. For example:—

Water, being composed of hydrogen and oxygen, is a compound substance.

Carbon is the main element of organic nature, whether animal or vegetable. Every living thing, from the smallest to the largest animal, and from the moss to the largest tree, contains this element as a most necessary part of its structure. It is found not only in living things but in their fossil remains, such as coal. In the uncombined state, pure carbon is found in the two very different forms; as first, diamond; second, graphite or plumbago. Carbon also occurs more or less pure in lamp-black, charcoal, coal and coke. In this condition it is porous, absorbs gases, is valuable as a disinfectant, and as charcoal, coal or coke, it is used as a fuel and burns in ordinary air at temperature corresponding to the red heat of iron.

Oxygen is the most widely distributed element in nature, and it exists in very large quantities. It forms between forty and fifty per cent of the solid crust of the earth, eight-ninths of the water, and about one-fifth of the air. Oxygen is an invisible, tasteless gas and has no odor. It is slightly heavier than air. For equal volumes of air and oxygen, the oxygen will weigh 1.1066 times as much as the air. Under very high pressure and a very low temperature it becomes a liquid. Oxygen is necessary to animal life and combustion; without it for breathing purposes, all animals would die, and as it is the element which supports combustion, nothing could burn without it.

Hydrogen is found in nature in large quantities, and very largely distributed. It forms one-ninth the weight of water and it is contained in all substances which enter into the combination of plants and animals. Hy-

drogen is a colorless, tasteless gas, and has no odor. It is the lightest known substance, being fourteen and one-half times lighter than air and sixteen times lighter than oxygen. In order to burn hydrogen, it must, like wood and other combustible substances, be heated to the kindling temperature before it will ignite or take fire. The hydrogen flame is colorless or very slightly blue. When hydrogen burns it combines with oxygen and forms an invisible gas, which, when condensed, will be found to be ordinary water. Hydrogen forms about fifty per cent of coal or illuminating gas, or about one-half of the gases distilled from the coal in the firebox.

Nitrogen is a gas which has neither color, taste nor smell. It will not support combustion, neither will it burn. The air is composed of about twenty-one per cent of oxygen and seventy-nine per cent of nitrogen. An animal would die if compelled to breathe simply nitrogen, for the reason that it will not support respiration. It is very useful in the air, however, as it dilutes the oxygen, thus making the process of combustion less active than it otherwise would be. Its usefulness lies not in what it does itself, but in its preventing the oxygen of the air doing too much. If the proportions of oxygen and nitrogen were reversed, most substances now used as fuel would be destroyed by oxidation (slow combustion or rusting), before they could be utilized in combustion, and the air entering our lungs, would, simply by too rapid combustion, shorten rather than lengthen our lives.

The element sulphur, is a yellow, brittle substance, which is almost colorless at fifty degrees F. below zero. It melts at 114½° F., forming a thin, straw-colored liquid. When heated to a higher temperature, it be-

comes darker and darker in color, and at 250° F. it is so thick it will not run. At 448.4° F. it boils and is then converted into a brownish yellow vapor. Sulphur is found as an impurity in most kinds of coal and by acting as a flux on other impurities of the coal it aids in forming the troublesome "clinker."

Water is made of two parts of hydrogen to sixteen parts of oxygen, by weight, or by volume, two volumes of hydrogen to one of oxygen.

Air is the gaseous substance which fills the atmosphere surrounding the earth. It has no color, taste or smell. It is made up by weight, of oxygen 20.61 parts; nitrogen, 77.95 parts; carbondioxide, .04 parts, and water 1.4 parts and a slight trace of a newly discovered gas called Argon, of which little is yet known. Air is never perfectly dry, but always contains a varying amount of water vapor. It is estimated that the air or atmosphere extends to a height of from fifty to 200 miles. By virtue of its weight it produces a pressure in all directions at the sea level of 14.7 lbs. per square inch, or about one ton per square foot. 13.6 cubic feet of air at 60° F. weighs one pound.

Combustion is a word applied to any action whereby the element oxygen combines with any other element. Combustion is ordinarily understood to mean the act of burning fuel, such as wood, coal, etc. Quick combustion or ordinary burning, is simply oxygen of the air combining rapidly with the carbon or gases of the fuel.

Oxygen will not combine readily with other elements at ordinary temperatures, and in order that they may combine rapidly, their temperature must be raised to what is called their burning or kindling temperature. If this were not the case combustible substances would

immediately burn up, as the air contains a sufficient quantity of oxygen for this purpose. If a piece of wood or coal is put on the fire, it will not burn until the temperature with which it combines rapidly with oxygen is reached, when it combines to burn. Watch a stick of wood burning and it will be seen that the fire creeps slowly along it. The reason for this is that only the portion of the stick nearest the burning part becomes heated to the kindling temperature. Different kinds of fuel have different kindling temperatures; a fact which should be remembered.

Coal gas will not burn below a temperature corresponding to the red heat of iron, and carbon has a still higher kindling temperature. The hydro-carbon gases given off from coal when burning, require for combustion a temperature corresponding to the cherry heat of iron. In order to burn coal it must be kept at a higher temperature still. The active portion of a fire in a firebox is constantly giving off gases from the fuel which require a high temperature for their combustion. Where these gases are burned in the firebox they give off a great deal of heat, but when the temperature of any part of the firebox is so low that the gases pass away unconsumed, there is a great waste of heat, and extra coal must be used to make up for this waste. A fireman, therefore, should never let the temperature in any part of the firebox fall below the kindling temperature of the fuel and the gases given off by it. It is a mistake to think that the temperature of a firebox is always hot enough to give complete combustion. Cold air coming through a thin fire may not be heated to the proper temperature, and when it touches the gases in the firebox it chills them, reducing their temperature below the kin-

dling point and they pass off unburned. If "a heavy fire" be given, the cold material chills the gases given off by the hot fire beneath and they pass off unburned in the form of smoke and coal gas. The firebox sheets carry away the heat of the coal next to them so quickly that the gases given off in those parts of the firebox are liable to be wasted unless the fireman keeps a bright fire in the vicinity of the sheets.

It is to be remembered that a body gives off light only when heated to a sufficiently high temperature. The question naturally follows, is there any difference between the quantity of heat given off when a substance burns, and when it undergoes slow oxidation without giving off light? There is no difference whatever. In quick combustion the heat is all given off in a short space of time, and the temperature of the substance becomes high and it gives off light. In slow combustion (oxidation or rusting), heat is given off slowly for a much longer time, therefore, the temperature of the substance does not rise very high, as the heat is carried off by the surrounding air and adjacent objects as fast as it is produced. If the total quantity of heat were to be measured, however, we would find it to be equal in both cases.

Combustion is the result of oxygen of the air combining with the carbon and hydrogen of the fuel. If fuel be heated to the kindling temperature, oxygen from the air will combine with the carbon and hydrogen of the fuel and cause combustion, or burning. This is due to the fact that all elementary substances, such as hydrogen, carbon and oxygen, have a strong attraction for each other when heated, and tend to enter into combination to form some compound substance.

When oxygen combines with any substance, we have either quick or slow combustion, depending upon the rate at which the action takes place. Combustion always gives off heat, and the quicker the combination the higher the temperature produced. This is one reason why a large piece of coal does not make as hot a fire as it would were it broken into small pieces. The smaller pieces of coal present more to the action of the oxygen, and consequently, they combine more rapidly, and as the temperature produced depends upon the rapidity with which the coal burns, the smaller coal will make the hotter fire.

It is a law of chemistry that the elements always combine in certain definite proportions. These proportions vary with the different elements, but any two elements will always combine with each other in a definite proportion or a multiple of that proportion. Thus, oxygen always combines with other substances in proportions by weight of eight, sixteen, twenty-four and thirty-two parts, all of which are a multiple of eight. Carbon always combines in proportions by weight of six, twelve, eighteen and twenty-four parts. Eight parts by weight of oxygen will combine with six parts of carbon, or sixteen parts of oxygen will combine with six parts of carbon, but fourteen parts of oxygen will not combine with six parts of carbon. If eight parts of carbon are mixed with eight parts of oxygen, six of the eight parts carbon will combine with eight parts of oxygen, but the remaining two parts of carbon will not combine. This would be called incomplete combustion, and is caused by not having sufficient oxygen to completely burn the carbon.

To obtain perfect combustion of coal, the following conditions must be observed: First, a sufficient supply

of air must be admitted to furnish enough oxygen for complete combustion; second, this air must be admitted in the proper location; third, sufficient time must be given for the combustible gases to completely burn when properly mixed with the air. The elements of carbon and hydrogen furnish about all the heat that is obtained from burning coal. If both are completely burned, the coal furnishes all the heat of which it is capable. If either one or both are not completely burned, part of the heat that should be furnished by the coal in burning passes off in the unburned gases and smoke and is wasted.

When coal is thrown on a fire, before any burning can take place, the elements of the coal must be separated, as they always burn in the order of: First, the gases which are distilled from the coal, and combine with the oxygen of the air admitted, and, secondly, after the gas has burned, the coke remaining burns also by combining with the oxygen, forming carbonic acid gas. The air admitted to the firebox mixes with the gases given off by the coal. The little atoms of gas combine with the atoms of oxygen from the air, generating sufficient heat to produce a little point of light, and the continuous combustion of the countless atoms of gas and oxygen in the different parts of the firebox produces a great number of points of light, or what is known as a flame. A bright flame in the firebox is an indication that the gases are burning, while a dull or absent flame and the presence of smoke, indicate that the gases are passing away unburned. If the gas does not have sufficient time to mix, atom by atom, while in the firebox and at the kindling temperature, smoke will be produced. Time effects the burning of the gases, for the moment they are driven off from the coal they begin traveling to-

wards the open air, and thus have but a fraction of a second in which to mix and burn while in the firebox. The coke, however, remains in the firebox and has its own time in which to burn.

When more air than is necessary to produce complete combustion is admitted to the firebox it reduces the amount of steam generated, in two ways: First, by reducing the temperature of the gases, and second, by increasing the volume of gases which pass through the boiler tubes. The greater the volume which must pass through the tubes in a given time, the greater must be their velocity, and consequently, they remain in contact with the heating surfaces of the boiler for a shorter interval of time. Reducing the temperature of the gases and the time of contact with the heating surfaces, reduces the amount of heat given to the water, and consequently, the amount of steam generated. The ill effects of admitting too much air to a fire may be seen by opening wide the damper and draft of a stove when the fire is very low; the large volume of air rushing into the stove not only cools the gases, but actually cools the fire itself, reducing the temperature below its burning temperature, thus causing the fire to go out.

When a match is lit and then blown out, what happens? The friction between the sulphur and whatever it is rubbed against heats the sulphur to its kindling temperature, which is low, and the sulphur burns, heating the wood to its kindling temperature and causing it to take fire. When the match has been used and we wish to quench the flame, we generally blow on it. The strong current of air coming in contact with the flame and heated wood, carries away the heat from both at such a rate that their temperature is reduced below that of kindling and

the match goes out. Blowing out a match is then but another instance of supplying too much air for combustion.

As before stated, when sufficient air is supplied to a fire, part of the gases must pass off in an unburned condition and a great deal of the coal is wasted. Particles of solid carbon, which are also set free and which are unable to burn for lack of oxygen, assume the form of soot and pass off as a cloud of smoke. Had sufficient air been supplied, this carbon would have burned and the heat thus generated, instead of being wasted, would have been utilized in forming steam.

A lamp chimney is used to produce a current of air against the flame of the lamp, so that sufficient oxygen is supplied to combine with all the particles of carbon set free from the oil. If either the bottom or the top of the chimney be partially closed so that the quantity of air admitted to the flame is insufficient to give complete combustion, the lamp will smoke. This illustrates what has been previously said about smoke.

The quantity of air admitted to a firebox depends upon the composition of the coal and the amount to be burned in a unit of time. Different kinds of coal require different quantities of air for complete combustion, the amount depending upon the kind of fuel used. Again, the quantity of coal used will depend upon the work being done by the engine, and as it requires an increased quantity of air to burn an increased quantity of coal, it will be seen that the air supplied must vary with the work required of the engine and therefore cannot be a fixed quantity.

Theoretically, the quantity of air necessary to completely burn one pound of carbon is twelve pounds by

:ight, or 150 cubic feet by volume. The theoretical antity of air necessary to produce complete combus-n of one pound of carbon is not the quantity that will ve the best results with a locomotive, however, as has en found by experience. The results of a number of periments made with a view of determining the proper antity of air to produce the best results seem to in-:ate that eighteen pounds or 225 cubic feet of air per und of coal is the quantity, if admitted in the proper inner. The proper quantity in any particular case of :omotive working can be easily noted by a careful fire-in through observation of the results in smoke.

It is to be remembered that to obtain the best results om coal burned in a firebox, sufficient air must be sup-ed to burn both the coke and the gases. If the coke me were to be burned, sufficient air for this purpose ald be admitted through the grates, and coal by reg-iting the thickness of the fire on the grates. To burn gases, however, an additional amount of air is re-ired. If, now, the thickness of the fire be so regu-ed that sufficient air is admitted through the grates burn both the coke and the gases when fresh coal is pplied, the fire will be too thin and will admit too much after the gases have been consumed. Again, if the e be kept so thin that sufficient air for combustion is mitted through the grates, it will be almost impossible keep the fire level and free from holes when the en-ie is working hard, as the blast will carry the lighter rticles of coal from the grates through the tubes un-rned, thus making holes in the fire and permitting a oid inflow of cold air when and where it is least de-ed. It is evident, then, that sufficient air for com-:te combustion of bituminous coal cannot be admitted

through the grates alone, and that an additional amount therefore, should be admitted above the fire to complete the combustion.

When air is admitted above a fire, it must be introduced in such manner that it will at once mix as completely as possible with the gases in the firebox, otherwise it will do more harm than good. If it is admitted in a large stream, as when the firebox door is opened, the air will not mix with the gases, but will form a distinct current of its own, just as water from a river forms its own current in the large body of water into which it empties.

The gases can only come in contact with the outer surface of this cold draft of air, and, without mixing, will be cooled below their burning temperature and pass away unconsumed. If the air above the fire be admitted through a number of small openings, it will mix more readily with the gases; will be heated to the proper temperature more rapidly, and will give more complete combustion than if admitted in a large stream. As the air admitted above the fire is used almost exclusively in burning the gases it should be regulated in amount so as always just to accomplish its purpose.

The volume of gases is greater just after firing than just before and consequently more air will be required just after firing to completely burn the extra amount of gases. In order to produce the best results then, the air required for combustion should be admitted as nearly as possible after the following plan: First, the thickness of the fire should be regulated, if possible, so that sufficient air for combustion of the coke of the coal may be admitted through the grates. This will require a thin fire evenly distributed. Secondly, sufficient air should be

admitted above the fire in small streams so as at all times just to complete the combustion. This requires that the quantity of air admitted above the grates shall be varied as the quantity of gases vary: Thirdly, the total quantity of air admitted through the grates and above the fire, should vary with the quantity of coal to be burned and should at all times be just sufficient to give complete combustion. All air which passes through the firebox must receive heat, and if more air than is required passes through it, it will absorb and carry away heat that should be used in making steam.

Experience proves that an engine may consume a large quantity of fuel without perfect combustion taking place, and that when it does take place, a portion only of the coal is used in making steam. The principal causes of the losses of heat during combustion are: First, small pieces of unburned coal which fall through the grates or are drawn through the tubes by the blast unconsumed; second, in the unburned gases passing off in a gaseous or smoky state; third, in the heat which the hot gases contain when they escape through the smoke stack; fourth, the loss of heat by radiation and convection from the boiler, due to the fact that the firebox is not sufficiently covered with lagging to prevent radiation and convection of heat from the hot boiler plates.

None of these losses can be entirely prevented, but the losses due to unburned coal, unburned gases, and radiation and convection may by proper means be very much reduced. There must always be a great loss of heat due to the hot gases carrying away heat, and a fireman can do but little to reduce this loss. By permitting just the proper amount of air for combustion to pass through the firebox, he may reduce it somewhat. The loss due to

unburned coal may be prevented by wetting the coal and breaking it into lumps which will not pass through the grates, and by keeping the fire of such thickness that the blast will be unable to pick up pieces and force them through the flues. The loss due to unburned gases and smoke may be prevented by regulating the amount and distribution of air admitted to the firebox.

The quantity of heat wasted, due to the several causes already mentioned are as follows: The amount lost by radiation and convection may be anywhere between five per cent and ten per cent; the heat lost in the hot ashes, clinkers, and by coal falling through the grates and being drawn through the flues, from five per cent to fifteen per cent; the waste due to the gases escaping at a high temperature through the smoke stack will vary from twenty-five per cent to thirty per cent; that due to incomplete combustion will vary from five per cent to fifteen per cent. From this it may be seen that in general practice about only forty-five per cent of the heat of the fuel is utilized in making steam, while the remaining fifty-five per cent is lost.

A fireman handles anywhere from six to twenty tons of coal per trip, out of which he uses but forty-five per cent, or four and five-tenths out of ten tons in making steam, the remainder, or five and five-tenths tons, being lost. It is true that part of this loss cannot be prevented, yet it is also true that a goodly share can, in some cases, be charged directly to carelessness or ignorance of the laws of combustion on the part of the fireman. Suppose this fireman makes 300 trips a year, using ten tons of coal per trip. The total quantity of coal used per year will amount to 3,000 tons, out of which fifty-five per cent, or 1,650 tons, are lost or wasted. If, now, by

careful management and skillful firing, this 1,650 tons is reduced ten per cent, there will be effected a saving of 165 tons of coal per year per engine. For every 100 engines this saving would amount of 16,500 tons per year, and with coal worth $2.00 per ton the saving effected would amount to $33,000 per year for every 100 engines.

Smoke is the volume of vapor and gases out of the smoke stack, colored by particles of carbon or soot. The color of the smoke depends entirely upon the quantity of carbon present. When a large quantity of fresh coal is thrown on a fire, it absorbs heat very rapidly and reduces the temperature of the firebox to such an extent that all flame is extinguished and a black vapor formed. Now, as before stated, the presence of flame and absence of smoke is an indication that the gases of the coal are being burned, while the absence of flame or presence of smoke is an indication that the gases are passing away, unconsumed. The black vapor or smoke seen in the firebox is of a different composition than the real smoke issuing from the smoke stack. The vapor or gas of the coal in the firebox is a mixture of hydrogen and carbon (carburetted hydrogen) colored by tarry matter, sulphur, and other volatile ingredients. When the carburetted hydrogen gas is heated to the kindling temperature, its hydrogen combines with the oxygen of the air, forming water which passes off as an invisible vapor. Part of its carbon which is liberated is burned, while the remainder passes away in the form of soot, coloring the invisible gases and forming what is properly called smoke. If sufficient oxygen is present in the firebox and at the proper temperature when the hydrogen gases are liberated, all the carbon will be consumed and the smoke prevented.

Smoke is an indication of imperfect combustion, and consequently of a waste of fuel. Without air there can be no combustion and therefore no smoke. With just the proper quantity of air there will be perfect combustion and no smoke; with either too much or too little air, there will be imperfect combustion and, consequently, smoke will be produced.

The absence of smoke generally indicates that perfect combustion is taking place, yet there are times when incomplete combustion takes place without the presence of smoke. If the draft is regulated so as to choke the fire, and sufficient coal is thrown on to cool the furnace below the kindling temperature of the hydro-carbons, there will be no flame and the hydro-carbons will pass off unburned, without producing smoke. This is a very wasteful method of preventing smoke, however, as the hydrocarbons amount to fifteen to forty per cent of the coal, besides the added disadvantage of making steam slowly and irregularly. The draft should always be increased instead of diminished, immediately after firing, so as to make sure of the hydro-carbons being consumed.

On most lines a large proportion of the number of engine failures is charged to "Not Steaming." While this report covers a multitude of sins, there is no question but that on many lines there is not sufficient care taken to insure the uniform good steaming of all locomotives. Yet the matter of good steaming is closely related to fuel economy, for there is a satisfaction and confidence in firing a good steaming locomotive which impels a man to show what he can do; while with a poor steamer the most expert and conscientious fireman will burn more coal in the endeavor to furnish steam than he would with a good steamer, and in the disgust at the always doubtful success of his efforts, he loses interest.

Where engines are not steaming, it is always the fault of either the management or the crews, or both. Locomotives can be designed which will steam successfully with practically any quality of coal. A locomotive designed for the development of a practical maximum power with a grate area which involves the burning of 14,000 B. T. U. coal at the rate of over 180 lbs. per sq. ft. per hr., however, cannot be made to furnish steam for an equivalent rate of working with 10,000 B. T. U. coal. Equally, a locomotive designed for a certain rate of working with a grate area intended for the use of 10,000 B. T. U. coal at a combustion rate of 100 lbs. per sq. ft. per hr. will prove wasteful of fuel with 14,000 B. T. U. coal at this rate of working, because of the small nozzle which will be required to induce sufficient draft to overcome an impractically low rate of combustion when working at half maximum power. This latter is not generally appreciated by technical men, but firemen have well observed that below a combustion rate of 50 lbs. per sq. ft. of grate area per hr., the fire does not remain in that state of incandescence essential in locomotive practice. It bakes and lies dead on the surface.

It is not meant to imply that the ordinary locomotive is unduly restricted to the use of a certain quality of coal for the insurance of steaming well, for most locomotives are designed with a grate area (and a concomitant amount of heating surface) of an extent which lies so well between the limiting rates of combustion, that good steaming can be secured throughout a considerable range in coal quality—if the drafting arrangements are varied to correspond with the variations in the coals. And it is in the roundhouse reporting of matters in this regard that poor steaming locomotives are often the

fault of the crews. How usual it is to note on the roundhouse work report book the simple statement, "Not steaming"! The author thinks frankly that an engineer making such a report deserves discharge, for everyone connected knows that the poor steaming may be due to any one or all of a dozen causes, many of which cannot be located by the roundhouse foreman because it is necessary to observe the engine under steam and working in order to diagnose the trouble. The engine crew have had this opportunity and if the specific cause for the failure of the engine to steam (where others of the same class steam well with the same coal) is not reported by the engineer, he is either too ignorant or too careless to be retained in charge of a locomotive.

It being obvious that a locomotive must be in reasonable condition and reasonably run in order for a fireman to accomplish satisfactory results and, the running of a locomotive from the standpoints of both engineer and the dispatcher being out of the province of these articles, we will hence concern ourselves solely with such aspects of the locomotive condition as the engine fireman is expected to deal with and hence have knowledge of.

The amount of ash pan opening, as well as grate opening between the fingers thereof, are matters of experiment which should be (and generally long since have been) established by the mechanical, or traveling engineer—and hence may ordinarily be neglected by the engine crew. The next point of observation is logically, the state of the staybolts and boiler tubes with respect to leakage. In good water districts this is not so much a problem as is the case in districts where the water supply is more or less bad. Where staybolts and boiler tubes are addicted to leaking, the matter of fuel econ-

omy must be deferred until the management is able to provide a better water supply. For where a justifiable fear of leakage is in existence, the matter of fuel economy is considerably less important than the necessity insuring that the locomotive gets its train over the division.

With a locomotive addicted to leaking, the secret of success in getting over the road lies in "keeping her hot" —all the time—up hill—down hill—in side—tracks— while switching—every place and all the time—to keep her hot from the time she is first taken until landed at the other terminal. If, in reaching the locomotive for a trip, the tubes or staybolts are spurting, it had better be turned back to the roundhouse, for a trip would almost certainly result in failure. If, however, the tubes or staybolts are merely "seeping," a hot fire will generally cause an amount of sheet expansion that will stop the leakage—and the prevention of leakage again developing is merely a matter of constantly maintaining a temperature in the firebox which will prevent this sheet expansion from becoming reduced again.

This is easily understandable if we recollect that the tubes and staybolts are fitted to the firebox sheets when the metal is cold, or contracted. Good water lies up close to the sheets and thus abstracts the heat from sheets as fast as evolved by the fire. Hence the sheets do not become heated much above the temperature equivalent of the water, and, therefore, the junctions of tubes and staybolts with the sheets are not distorted beyond a capacity to return to their original tightness when the temperature of the fire drops. Bad water, however, either deposits a heavy scale, or else boils away from the sheets (generally both). This results in the water not abstracting the heat from the sheets as rapidly as it is

transmitted by the fire. Hence the temperature of the sheets rises considerably beyond that of the steam temperature equivalent and, the resulting expansion is so great that the junctions of the tubes and staybolts with the sheet are distorted beyond their ability to return to the original tightness and leakage results. The temperature of steam or water at 200 lbs. pressure is 387 degrees. D. K. Clark gives the temperature of 14,700 B. T. U. coal as follows when burning at certain rates:

Lbs. of coal per sq. ft. of grate area per hour.	Temperature of surface of fire in degrees Fh.
40	1,857
80	2,009
120	2,097
160	2,137*
200	2,157*

*Would be "about."

So that unless the water takes the heat away from the sheet as rapidly as delivered, the temperature (and the consequent expansion) of the sheet will rise very quickly above that of the surrounding water. Now, in the table just quoted it will be noticed that the temperature of the fire does not drop very rapidly until we burn somewhat less than 80 lbs. of coal per sq. ft. of grate area per hour. As the blower will generally enable a combustion rate of more than 40 lbs. of coal per sq. ft. of grate area per hr. to be maintained, the drop in fire temperature, which will start a "tender" set of tubes to leaking, can be avoided—where merely getting over the road becomes more important than fuel economy. Firemen will readily remember the manifestations here

explained in cases where an engine stops leaking when working hard, but starts leaking soon after shutting off unless the blower is put on.

Another difficulty encountered with some fuels is "honeycombing." The author confesses himself unable to say anything of particular value in regard to this difficulty. He has heard it said that a percentage of lime mixed in with the coal will obviate or considerably reduce the honeycombing, but he has never seen it tried and hence does not vouch for the suggestion. With some coals, honeycombing develops into a very serious matter, especially in passage service over long divisions. In freight service there is generally opportunity around stations to knock off the major portion of the clusters with a bar, while in passenger service such work must perforce be done while rolling down hill, which is consequently a very disagreeable job. The use of brick arches considerably reduce the tendency to honeycomb, and are hence advisable where such a coal is used in passenger service. But in freight service they block the efforts of the fireman to knock down the honeycombing so effectually that it is generally a better policy to leave them out where it is necessary to use a honeycombing coal. One thing is certain, however, in this connection, viz.: that the roundhouse force should be compelled to furnish the locomotive thoroughly free from honeycombing when delivered to the engine crew.

Mention of the brick arch suggests a few remarks in connection therewith. The arch has several functions. It is put in in order to retard the gases of combustion by compelling them to travel a greater distance around it before reaching the boiler tubes. When once the gases have entered the tubes, no further progress of combustion

is possible, hence the longer they remain in the firebox the greater opportunity there is for the combustion processes to complete themselves. Furthermore, when the arch has become heated, it affords a highly heated surface for the gases to impinge upon and thus be assisted in the completion of the process of combustion. The arch also heats the air entering through the firedoor and tends to deflect it downward toward the bed of the fire, and, at the same time throw the air and gases into a more thorough mixture. The arch also protects the tube sheet from being directly struck by the cold air entering the firedoor, and also from the effects of letting fire die down while drifting or lying around stations. In some road tests made by the author on an old style, 16 by 24 ins. eight-wheel locomotive, in passenger service, the locomotive evaporated 7.5 lbs of water per lb. of coal, without an arch, and 8 lbs. with one. The arch increases the difficulty of firing to some extent in certain types of fireboxes, and, until one gets used to firing with the arch in place, considerable coal is landed on top of the arch, or the grate surface next the tube sheet allowed to become exposed. One soon becomes accustomed, however, to avoid these faults. The arch should be watched, however, and any symptom of its breaking down immediately reported in order to avoid trouble on the road.

Where the arch is used, the state of the tubes in regard to their being stopped up cannot be observed by the crew until the locomotive is started working. And even without the arch a considerably greater number of tubes may be choked than the few observable from the door. While a badly stopped up set of boiler tubes will cause remark from one who knows the engine, by

the slow effect of the blower, yet one unfamiliar with the engine in its normal condition would be inclined to attribute such a symptom to a weakness of the blower. The most satisfactory specific way to observe the state of the tubes in this regard is by the lag in the appearance of black smoke after shutting off after the engine has been working hard. If the fire has not been prepared for shutting off and if the door is not then opened and the blower put on, a locomotive whose tubes are not stopped up to any extent, will almost instantly pour black smoke out of the stack. If the tubes are pretty well stopped up, however, there will be a more or less great lag in this appearance and volume of this smoke.

This matter of choked tubes is one of the most annoying, yet most common, occasions for controversies between the roundhouse and the engine crews that the author can cite. Obviously, every choked tube is that percentage of the boiler's tube heating surface out of commission. Any practical man will admit that the eye alone will point out 25 choked tubes in five locomotives out of 10 on practically any road in this country. If 25 tubes are choked to an extent which is visible at the tube sheet end, it would be a safe bet that there were anywhere from 50 to 75 more through which the gases could not pass; and if the gases cannot pass through a tube it is useless. This would mean 100 useless tubes. In a locomotive with 2,500 sq. ft. of tube heating surface from 300 tubes, this would mean one-third of the heating surface rendered valueless, or, instead of the 2,500 sq. ft. of tube heating surface, the boiler has practically but 1,667 sq. ft. of tube heating surface. No wonder there are so many reports of engine failures because of not steaming.

There is much improvement to be desired in roundhouse methods on this point. The importance of clean tubes is not appreciated, the roundhouse facilities for the rapid and easy accomplishment of a thorough job of tube cleaning are hopelessly crude in nine out of ten roundhouses on every line in the United States, and the class of men assigned to these jobs are absolutely irresponsible in the absence of the checking up which is imperative, but not given. The result is that the tubes *are not cleaned* when reported. The author feels very strongly on this subject, as a result of several mortifying experiences needless to relate here. It might be well, however, to point out the absurdity of the average roundhouse procedure on a report of "Flues are stopped up." If the arch is in good shape the foreman is greatly averse to undertaking the job and will avoid it if possible, and hence orders the useless expedient of poking a rod through the top tubes which can be reached, and the insertion of a hammer handle in the lower tubes which are filled up. If the state of the locomotive as regards steaming, however, forces some action, the two least reliable laborers on the place are set at the job with "augers," which, being but half the diameter of the tube, merely half clean such tubes as are entered, and—as there is practically no attention given to their efforts they loaf on the job, skip all the "hard ones" and more than half the "easy" ones. Even if air, steam, or water is furnished for blowing out, instead of boring the tubes, the dirt of the job causes it to be scandalously slighted. The result is so perfunctory an accomplishment of this work as to greatly discourage engine crews in reporting it and often to incline them to merely ask instead for a smaller nozzle tip, or for a bridge therein.

Next to choked tubes, though not as often in evidence, the leaking of a steam pipe joint is the most absolute bar to a free-steaming engine. While standing still, the placing of the reverse lever on center and the opening of the throttle will enable the blow of the joint to be heard if the valves are tight enough to prevent the steam from blowing through them and thus drowning out the blow from the steam pipe joint. While working, a leaky steam pipe joint evidences itself to blocking the draft to an extent which causes the fire to burn as if the nozzle tip were too large, while the steam fails more rapidly in the presence of this defect than from any other. The location of the leak can only be securely placed by opening the front end door, while steam is given with the engine on center, when it can be heard and seen or located with a torch.

The deflection, diaphragm, or baffle plate, as variously called, controls the level burning of the fire on the grates. If the locomotive burns more coal at the rear of the grate surface than it does in the vicinity of the tube sheet, the deflector does not extend down far enough and should be reported for lowering, say an inch. If, on the other hand, coal is burned more rapidly in front than in rear, it should be raised. The reason for this is simply that raising the deflector allows a greater amount of draft through the upper tubes, which have their effect chiefly over the rear of the grate surface, while lowering the plate decreases the draft through the upper tubes, and, therefore, the draft over this rear portion of the grate surface.

The size of the exhaust nozzle tip has been the subject of much investigation in its location as respects height, with regard to the size of the stack and the general arrangement of the front end. So far as the fire-

man is actually concerned in utilizing the arrangements furnished him, however, the proposition is simply that on the size of the nozzle tip depends the amount (or rather, intensity) of the draft. Since the force with which the steam passes through the nozzle tip depends on its size with relation to the volume of the cylinders, the pressure on the exhaust sides of the pistons will decrease as the size of the nozzle tip is increased. Naturally a large nozzle means low back pressure in the cylinders and a mild draft on the fire, which latter means, of course, a slower rate of combustion than where a smaller nozzle tip (or a bridge) is used. If, however, the nozzle tip is too large, enough draft will not be furnished to burn the coal fast enough to cause the engine to steam freely. Then the size of the tip must be decreased, regardless of the question of cylinder back pressure. A skilful and careful engine crew who are familiar with the locomotive can run with a larger nozzle tip than a less experienced or more careless crew, and get far better results both in the way the engine handles the train and in the amount of fuel consumed. This leads the officials and the more skilful engineers to have a great prejudice in favor of a large nozzle. Consequently, when a locomotive comes out of the back shop, or has been the regular engine of a skilful crew, it generally is equipped with nozzle tip larger than will provide sufficient steam for a less skilful crew, or possibly a poorer quality of coal than the size of the tip was intended for. Hence a report of poor steaming. Personally, the author goes against general practice by considering it a better policy to err on the side of too small a size of tip than in the direction of too large a tip—for the reason that a fireman will use more coal in endeavor-

ing to force an engine to steam with insufficient draft than he will where the draft is so strong as to give him no fear of not being able to make plenty of steam whenever required. Certainly if a locomotive does not burn its fire freely and it is not a case of choked tubes or leaking steampipe joints, there should be no hesitancy in insisting on a reduction in the size of the nozzle tip. There is no use in fooling with an engine that does not burn its fire.

There has been, is yet and probably always will be a lot of trifling with deflector plates and lift pipes in the endeavor to enable the use of a large nozzle tip. As a matter of fact, the area extent and size of mesh of the netting controls the size of the nozzle tip infinitely more than the other front end devices, yet little thought is ever given to the netting. In the effort to reduce the volume of the smoke box to an extent which will make the front end self-cleaning, the length of most front ends have been reduced to an extent which makes it impossible to supply the front end with an area of whose mesh is sufficiently fine to prevent fire-throwing with the coal used. Obviously, there should be a sufficient area of netting of a particular mesh to enable the total of the openings between the meshes to equal, if not somewhat exceed, the total area of the tube openings. Three hundred two-inch tubes are equivalent to an area of 6.545 sq. ft. The open space between the wires composing a three-mesh netting will be about .6 of the total area. Therefore, 6.545 should be increased by 40 per cent., or there should be at least 9.16 sq. ft. of this mesh netting in such a front end—and preferably a little more. Most locomotives will be found to have a smaller area of netting with respect to the area of tube openings than

this. The result is that the nozzle must be contracted in order to produce draft enough to pull the gases and cinders through an insufficient area of netting. An additional effect of such insufficient area of netting may be observed by taking off a hand-hole plate and looking into the front end when the engine is working hard. The lower surface of the netting will be observed to be more or less choked by a layer of cinders which are drawn up and kept dancing against the lower surface of the netting until broken into a fineness sufficient to pass through. Obviously, the more restricted the area of the netting the thicker this layer of cinders will be and will be then consequent effective in choking the netting.

The function of the lift, or petticoat pipe, or pipes, is not generally understood. There is a very general impression that it may be manipulated to increase the draft on the fire. This is entirely wrong, except the indirect effect on the fire by means of its action on the netting. The function of the lifting pipe is simply and solely to distribute and equalize the draft effect of the nozzle tip, over the full area of the netting. Without a lift pipe, that portion of the netting next the deflector plate will naturally receive a stronger draft than the portions of netting lying further away from the nozzle. Hence the full area of the netting will not be utilized in an equal degree. Where the lift pipe is used (and it should preferably be of the three section type) the draft induced by the exhaust is confined in the cylindrical portion of the lift pipe and its effect distributed over the whole area of the netting in an equable manner through adjustments of the flares with relation to the cylindrical portion of the pipe and the portions of the netting over which more draft is desired. Thus making the whole

area of the netting equally efficient, of course, results in increasing the draft on the fire. It has been a theory of the author that this function of the lift pipe in distributing the draft could be utilized in entirely doing away with the draft obstructing deflector plate, and by means of a low nozzle stand and netting reaching clear back to the tube sheet, depend on drafting the level burning of the fire entirely by the adjustment of the lift pipe—as was customary with the old diamond stack. Lift pipes may cause trouble by getting out of center with respect to the stack, thus throwing the exhaust to one side of the stack and confusing the equalization of the draft over the netting. When the upper edge is set too close to the stack base the face flow of the product of combustion into the stack is interfered with. The lower edge may be set so close to the nozzle tip as to too greatly muffle the draft over the portion of the netting next the deflector plate. They may be so large in diameter as to have little effect on the control of the draft distribution; they may be so small in diameter as to interfere with the entrance of the gases by the exhaust, and, finally, they may be made to cover so great a portion of the path of the exhaust as to destroy a considerable amount of the draft created by the exhaust. These points of sizes and adjustments are matters of experiment with each class of engine and often the finer adjustments become a matter of experiment with individual locomotives. But when such adjustment is once attained, the lift-pipe should be left strictly alone and, in case of a falling off in the free steaming, the trouble looked for elsewhere, unless the pipe has got out of line.

Bridges or splitters in the nozzle or stack are but expedients resorted to and encouraged by the roundhouse

to avoid the greater work of bushing the nozzle tip, or providing the engine with a smaller stack. Their effect lies solely in reducing the area of the nozzle tip or stack and they result in considerably more back pressure being thrown on the piston than is the case where bushings are used instead. A splitter in the stack creates a horrible sound and does more harm than good with a stack diameter which is less than the diameter of the cylinders. Where a nozzle tip or bushing is blown out on the road, the slice bar may be stuck down through the stack and into the nozzle stand to enable the first station to be reached, when it had better be removed and broken link heated and bent out so that one arm will rest on the netting, while the other extends down into the exhaust stand, when lowered in with a piece of bell rope.

As stated in the beginning, with a poorly designed locomotive, or one in poor condition, or adjustment of its draft arrangements, the skill of the fireman, perforce, is concerned chiefly with the production of steam, without much regard to fuel economy. Also, as stated, this may be the fault of the management, or the crews, or both. Managements can provide locomotives which steam freely with any quality of coal, if kept in proper condition and, if the engine crews assist the management in this keeping of the engines in proper condition in the ways here pointed out and in many other ways not in the province of these articles to mention, but readily called to mind by any man who has been around railroads long enough to get over being afraid of the noise. It may be said for railway managements, that as a rule, with negligible exceptions, the managements have furnished locomotives of sufficiently

near proper design as to enable free steaming with the character of coal used on any specific division—if the locomotives are kept in proper condition. Right here is where the engine crews are often more to blame than the management for the condition of the locomotives. The neglect of the roundhouse force to perform the work reported by the engine crews, engenders a disposition of the crews to omit reporting of anything but the loss of a couple of driving wheels. If, on the contrary, all the crews would conscientiously and persistently report every defect on the conclusion of a trip, the roundhouse force, or facilities, or both, will soon be observed by the management to be inadequate, with the result that these matters will assuredly be taken in hand with sufficient determination as to cause the development of a proper condition of affairs.

The foregoing pointing out of human and mechanical defects does not imply that such are all apparent everywhere. As a matter of fact, it is to the credit of both managements and engine crews of American railways, that a good ratio of triumph over these difficulties is maintained in the face of the abnormal business and (consequently) traffic condition of the past four years. That is to say, that the fireman generally is provided with a locomotive with which he can exhibit a reasonable degree of fuel economy—if he is competent and careful (the one trait being invariably the accompaniment of the other). Crews are much inclined to complain of poor coal. It has already been explained that practically any quality of coal can be made to furnish plenty of steam to the locomotives in service unless either the crews do not know enough, or are too careless to report what alteration or repair is needed to enable the locomo-

tive to steam freely, or else this reported work is not done. So it is within the province of the crews to obtain free steaming engines in one way or another, sooner or later. It is a matter which the management is compelled to submit to the judgment, as well as the skill, of the engine crews.

With a free steaming locomotive, and it has been endeavored to elucidate how such may be made the rule instead of a 50 per cent exception, the problem of clinkering, long hours on road, hauling the tonnage, or making the time and finally fuel economy, become simplified to an extent which can be comparatively easily handled by the crew. Take the matter of clinkering. A coal containing a considerable percentage of rock or slate will naturally leave these elements behind on the grates, as the combustible part of the coal burns away. The solution of the successful firing of such a coal is not to allow the clinker to remain in the box to an extent which will block the grates. Down hill in passenger service, or around stations in freight service, it is a comparatively easy matter to loosen up and hook out the spots of clinker as they develop to any extent. A pair of tongs for this purpose will invariably be supplied all engines leaving terminals, if the firemen get together and put it up to the divisional head of the mechanical department as a matter of grievance. If, through indisposition to take the matter in time and thus head off trouble, of course, the clinkering will rapidly reach a stage where a stop for a grisly job of fire cleaning is necessary, or else a failure for steam is developed. In this line the author is reminded of a grate arrangement on the C., B. & Q., whereby each rocking section of grate can be turned into a dump grate by means of a secondary grate handling

lever and reach rod, thus permitting clinkers in any part of the fire to be easily knocked through into the ash pan —even while running.

The matter of excessive tonnage is often cited as a cause of excessive fuel consumption. If the fire is kept clean the facts of the case are directly the opposite of such a statement. For locomotives are, perforce, designed with the intention of developing their most economical performance at the maximum rate of working. Furthermore, the proportion of coal burned per ton of freight hauled is, because of the lower speed that heavy tonnage implies, much less than is required in developing the higher speed of lighter trains. Of course the heavy tonnage implies longer hours on the road, but that is a much more matter of the density of traffic than of the bare train tonnage. In this connection it may be said, however, that recent intelligent analyses of the heavy tonnage proposition has shown that because of several other factors than fuel economy and the wages of crews, it is more economical on a busy line to reduce tonnage to an amount which will allow engines to get over the road at an average speed of from 12 to 15 miles per hour, than to load them down to an extent which will prevent such average speed being maintained. Hence we will doubtless see less of excessive tonnage in the future than has been in evidence in the past.

THE HOLLOW ARCH FOR LOCOMOTIVES.

Hollow arches, providing passages for the admission of heated air to the fire, *from above,* in addition to the air that comes up through the grates from below in the ordinary way, insure an economy of fuel and thereby effect a saving in operating expense. They keep the supply of oxygen at all times sufficient to insure a practically perfect combustion of the unconsumed carbon and hydrocarbon gases which are ordinarily wasted and lost in the form of black smoke pouring from the stack.

The problem of securing complete combustion of fuel on a locomotive, presents peculiar difficulties. The quantity of fuel to be burned is so large, and the firing space relatively so small, that ordinarily the conditions are unfavorable for economical combustion. A ton of average bituminous coal contains about 1,000 pounds of pure carbon, 700 pounds of hydrocarbon gases, and 300 pounds of non-combustible matter or ash. The 1,700 pounds of carbon and hydrocarbon gases require about 300,000 cubic feet of air for their complete combustion. Now, by the usual method of burning coal on a locomotive, fully 90 per cent of this air—or 270,000 cubic feet per ton of fuel burned—must be drawn up through the grates. This is practically impossible without forcing the draft to such an extent that the fire will be pulled off the grates, and more or less of the unburned coal carried away through the flues and stack. The result is that the supply of air actually used is as a general thing insufficient for perfect combustion, and the combustible carbon smoke and hydro-

carbon gases pass through the tubes and out of the stack without giving up all of their heat to the water in the boiler. The energy they contain is wasted. If their complete combustion inside the firebox and flues can be secured, this energy otherwise lost will be saved.

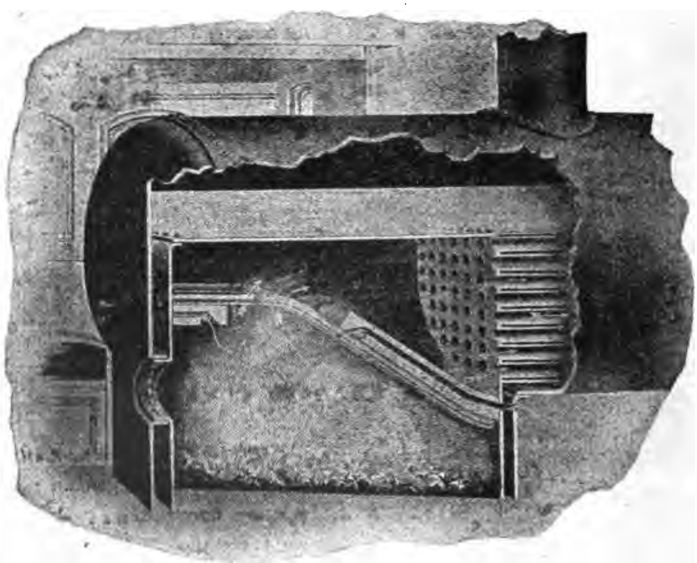

Figure 52. Wade Nicholson Hollow Arch for Locomotives.

How can this be done? In other words, since the quantity of air that comes through the grates is insufficient, how can we get enough air to the fuel without interfering with the fire? It must be let in *above the fire;* but it will not do to admit cold air directly from the outside, for, as every fireman knows, the effect of that is to act as a damper on the fire, combustion is retarded.

black smoke is formed, and a material loss of energy is incurred. The air to be admitted to the fire *must first be heated to as near the ignition point as possible.*

This is done by means of the *hollow arch.* One of these arches of the "Wade-Nicholson" type, installed on a locomotive, is illustrated in the accompanying cut. The device may be installed at both back and front ends of the firebox. The hollow passage through the arch leads

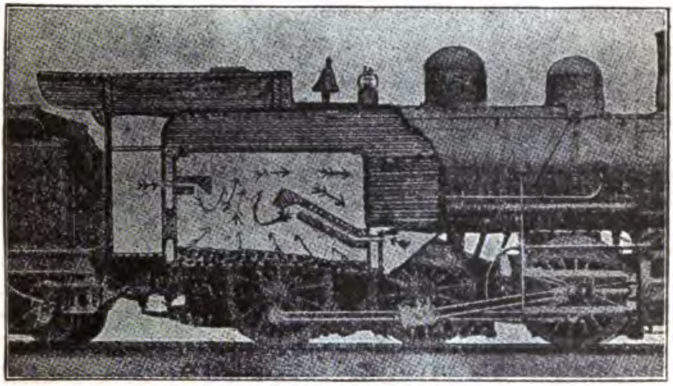

Figure 53. Showing Air Circulation in Firebox of Locomotive Equipped with Wade-Nicholson Hollow Arch.

directly through suitable openings in the firebox sheets, from the outer air to the combustion chamber, being deflected downward toward the fire at the inner end. The walls of the arch are highly heated, and impart their heat to the current of air, which, as it emerges into the firebox, is practically at the temperature of ignition. There mingling directly with the combustible gases, an approximately perfect combustion is established. The resulting economy in fuel is estimated to average a saving of at least 8 per cent.

Arches of the above type have, after severe test, been adopted by the Chicago & Northwestern Railway.

In addition to the saving in fuel, the following advantages are claimed for the hollow arch:

Being air-cooled, its life is two to three times that of the ordinary solid brick arch.

It does away with the smoke nuisance.

The air being heated before striking the combustible gases, unites with them instantly, giving a brighter, cleaner, more intense fire, and resulting in a better steaming engine.

The back arch acts as a baffle-sheet, protecting the crown sheet and upper flues, and gives a more uniform distribution of heat throughout, resulting in less leaky flues and a saving in boiler repairs.

The arch can be used either with or without the circulating tubes.

Arches can readily be removed and reset, in whole or in part, without damage, to give access to the flues when repairs are needed.

*CATECHISM ON COMBUSTION.

Question 1. What is combustion, or burning.

Answer. It is the union of that element of the air known as oxygen with the hydrogen and carbon of the coal, this union forming a gas.

Q. 2. What are the elements of fire, as considered in locomotive practice?

A. Quality of fuel, composition, distribution and application of air through the burning fuel to produce the greatest possible degree of heat with the smallest possible consumption of fuel.

Q. 3. Is there such a thing as perfect combustion?

A. No.

Q. 4. What is perfect combustion from a theoretical standpoint?

A. It is combustion that supplies just the required number of heat units to furnish a given amount of steam at all times to perform the required work without a fuel waste.

Q. 5. Why can it not be attained?

A. The manner of supplying the fuel to the fire at irregular intervals and in varying quantities; the loss that is continually taking place from imperfect combustion, which will be spoken of later: the variation of grades, load and speed, with consequent variation in cut-off and fuel consumption. While a heavy train means more money earned than a light one to off-set the increased fuel consumption a higher rate of speed increases the amount of

*W. L. French.

coal consumed without any increase in the earnings; so that it is evident from an economical standpoint fast trains are not a success. For these reasons perfect combustion is impossible in locomotive practice, and is not attained with stationary boilers where the engine load and speed is not variable.

Q. 6. What is meant by the term heat unit?

A. The amount of heat necessary to raise one pound of water one degree (Fahrenheit).

Q. 7. What is its equivalent mechanically expressed?

A. The power exerted to raise 772 pounds one foot high.

Q. 8. How many heat units does a pound of coal burned represent?

A. It varies with the quality of coal burned, but about 14,000 may be considered a fair average with the different grades of coal. With an excellent grade of coal where there was but very small loss from unburnable material it would run much higher, and with a poor grade the opposite condition would prevail in a similar degree. A good grade of coal that cost much more than a poor one is often the cheaper when the relative amount of heat units in the two are considered.

Q. 9. What is the amount of water evaporated for each pound of coal consumed?

A. Seven to eight pounds of water to one pound of bituminous coal burned; about one pound less water is evaporated per pound of anthracite coal.

Q. 10 What are the two most important elements in the production of combustion?

A. The carbon of the fuel and the oxygen of the air. These two elements have a strong natural affinity for each other, which fact aids greatly in the process of combustion

and producing both light and heat amid violent evolution of the gases, within the firebox.

Q. 11. What is the composition of soft coal?

A. About 80 per cent. carbon, 5 per cent. hydrogen, and the remainder may be classed as waste material, that is, incombustible matter.

Q. 12. What is the amount of air required to consume one pound of soft coal?

A. The exact amount can not be given in locomotive practice, owing to the varying conditions of the fire and the work, and the quality of the coal used, but from 12 to 18 pounds is a fair average. The rate of air admission must be proportionate to the coal consumption. Too much air, especially if admitted above the fire cools it and causes a fuel waste; too little air supplied causes imperfect combustion with a consequent fuel waste.

Q. 13. How much space does a pound of air occupy?

A. Thirteen cubic feet. Taking 12 pounds of air, the lowest rate of air consumption per one pound of coal, multiplied by 13 cubic feet, gives 156 cubic feet of air used for each pound of coal burned; allowing 20 pounds for a shovel of coal gives 3,120 cubic feet of air consumed for each shovel of coal burned, and on that basis 31,200 cubic feet of air for each ton burned. *The necessity of unrestricted air admission through the grates is obvious* to any one who cares to give the matter any consideration whatever.

Q. 14. How can the amount of carbon and hydrogen in coal be determined?

A. Only by chemical test. Therefore the comparison of coal sheets of parallel lines of road with varying grades and qualities of coal is no fair comparison in any sense of the locomotive performance.

Q. 15. Which is the lighter gas, carbon or hydrogen?

A. Hydrogen. It raises first and is first consumed of the gases of any given piece of coal, and a certain amount of moisture is consumed with it. The carbon is next burned, but the two burnings are so rapid as to be practically one and the same. Nothing in nature is destroyed. Its form only is changed. Coal by combustion is changed into heat and waste material; the oxygen of the air changes its form, and water is converted into a gas called steam, to be later vaporized and changed back to water by cooling. Always changed but no destruction of matter.

Q. 16. Is oxygen necessary for combustion?

A. Absolutely: It must also come in contact with whatever is to be burned, so that the admission of air is the important matter in combustion.

Q. 17. What change must occur with coal before it is burned?

A. It must be broken down, that is, the heat properties must be separated from the waste material, and heat is required to do this and by its application gas and coke are produced. Coke is known as the fixed carbon of the coal, and the waste material is designated as ash. The gas is carbon and hydrogen. The hydrogen and carbon in a ton of coal is equal, as before stated, to about 85 per cent. of the whole, or 1,700 pounds for one ton of coal.

Q. 18. What gas is formed by the proper mixing of oxygen with the gas from the coal?

A. Carbon dioxide. A colorless gas.

Q. 19. What result as to loss of heat does insufficient air admission to a firebox have?

A. A pound of carbon turned to carbon dioxide will convert 125 pounds of water into steam at a high boiler pressure, but with too small an admission of oxygen only

about one-third as much water will be evaporated under similar conditions, so that the fuel waste is enormous; therefore, the restriction of the draft area by reason of bad damper arrangement or handling, or from clinkered or heavy fire are expensive matters for the railroad companies financially, and physically for the fireman who makes the steam.

Q. 20. What three important things are to be considered as most essential in combustion?

A. The kind and quality of the fuel to be burned; the admission or furnishing of sufficient oxygen—the supporter of burning—to the fire, and the igniting temperature of the fuel burned.

Q. 21. What usually controls the kind and quality of coal burned?

A. Natural availability. Often a soft coal is used that shows a poorer rate of heating power than some other coal that must be hauled from a distance. However, it will make the steam by using more of it, and its availability over the other coal makes it cheaper per 100-ton mile even with a higher consumption.

Q. 22. What is the igniting temperature of bituminous coal?

A. Carbon 900 degrees. The two gases united as hydrocarbons 950 to 1,250 degrees Fahrenheit. These are only approximate figures for the different grades of soft coal, the kind most commonly used in locomotive service.

Q. 23. What part of the air is oxygen?

A. About 1-5th part. The source of supply is unlimited, but the same is not true concerning the source of admission. To meet this demand for abundant air admission and to meet the extra demand made by the use of large locomotives various plans were tried.

Q. 24. Explain some of these plans.

A. At first by increasing the length of the firebox to such a degree that it was found to be impracticable for efficient firing and combustion. To give the required grate area and shorten the box to reasonable proportions the shallow firebox extending out over the frame and rear drivers; or trail wheels on some types of locomotives with high drive wheels.

Q. 25. Has any other method of admitting air other than through the grates been tried, and with what result?

A. Admission by hollow stay bolts and by flues running from the atmosphere through the firebox sheets above the fire, and known as combustion flues. The all-hollow stay bolt is not used as much as formerly and the combustion flues are used in a milder degree.

Q. 26. Why are combustion flues used to a less extent than formerly?

A. The admission of air above the fire through a number of two-inch tubes was found to be more detrimental than beneficial, on account of such large currents or air cooling the fire and sheets and tubes of the firebox. Where the grate area is deficient, air admitted in small jets above the fire would be of benefit, as it would mix readily with the gases without cooling them to such an extent as is done by combustion tubes.

Q. 27. Why is air that has passed through the grates to the firebox preferable for the purpose of combustion?

A. Because in passing through the fire it becomes heated and is more ready to unite with the coal gases and take its part in combustion than that which is admitted above the fire. A certain amount of air admitted above the fire can be used without noticeable loss, but the heat loss is considerable when it is admitted in such quantities

as to cool the gases below the igniting temperature. All firemen know what the result of holding the firedoor open is on the fire.

Q. 28. What regulates the openings between the grate fingers in addition to the air admission?

A. The openings must not be so large as to allow coal to drop unburned in the ashpan. They should rock enough to shake small cinders and pieces of slate through readily.

Q. 29. How can the necessity for the immediate burning of the gases be illustrated?

A. As before stated, at a high temperature with plenty of oxygen admitted to the coal gases, carbon dioxide is formed with a heat value three times as great as where the supply of oxygen is reduced or the temperature is too low, and carbon monoxide is formed; they do not *wait* to be burned, but are at once carried forward through the flues and escape unobserved out of the stack to the atmosphere.

Q. 30. Why is escaping gas from a smokestack not noticeable?

A. Because it is colorless. Turn on a gas jet and watch if you can see the escaping gas.

Q. 31. Will gases be burned after once they have entered the tubes?

A. To no great extent.

Q. 32. Why?

A. Because of the low temperature within the tubes and the amount of heavy gas they contain. A light lowered into a well where there is a carbonic acid gas immediately dies, and so the blaze from the firebox enters the flues but a short distance and dies. That the temperature of the flues is low is demonstrated by the fact that flues

seldom, if ever, leak in the smokebox end, evidence that they are not subjected to the great temperature variations that they are in the firebox end.

Q. 33. Is a fire that gives off plenty of black smoke evidence that all the gases are being consumed and that it is the best kind for steam?

A. No. A fire that is in good condition will always give off some black smoke when a fresh supply of coal is put on the fire, but this will only be for an instant, unless a large amount of green coal has been used. Light firing will do away with much black smoke, which is an indication of too little oxygen for the amount of coal supplied and represents unburned carbon and a loss of heat.

Q. 34. Does black smoke represent all the heat loss that may be taking place?

A. No. Colorless gas may be escaping at the same time unnoticed.

Q. 35. Is there any economy or better steam results secured by "crowding" or over-firing an engine that is steaming poorly.

A. No. While it is very natural for a fireman when an engine lags on steam to shovel more coal than the fire can consume, the result is to only make a bad matter worse, by getting a bad fire and causing possible delay to clean it. It is all right to put in an extra amount of coal to determine if that is what the engine needs, but when the fact is once determined that something else is the cause of the engine's not steaming no one but an inexperienced man can be excused for overfeeding the fire. Yet many experienced firemen can not refrain from shoveling in more coal even when their judgment tells them that it is a detriment to the fire.

Q. 36. Does heavy firing always imply a fuel loss?

A. No. The work the locomotive is doing may demand the extra amount of coal being fired, which should be proportioned to the work being done and the fuel consuming capacity of the locomotive.

Q. 37. What would cause deficient air admission through the grates of a firebox where there was plenty of damper space, grate area, and openings to supply the needed amount of oxygen?

A. Coal fired in large lumps, very fine coal fired so as to cause a bank in the fire, grates covered thickly with ash or cinders, or an ashpan so full as to check the inflow of air through the dampers.

Q. 38. Why does coal in large lumps interfere with the air admission and good steaming qualities of a boiler?

A. Because coal must be broken down by heat before combustion takes place, and it is evident that a piece weighing 10 pounds will resist this breaking down much longer than a piece weighing one pound, just as it is easier to fire a small stick than a log. Also, where the large piece of coal lies on the grates no air can enter except around the edges, so that considerable air admission space is thus lost. Where coal is broken properly it gives the best result for air admission and combustion. If there is any doubt of it, try firing with big lumps and watch the pointer on the gauge go back.

Q. 39. Why does ash and cinder on the grates cause poor combustion?

A. Where they are allowed to accumulate on the grates oxygen is kept from the fire, and as the fire gets heavier they become packed and quite solid. All firemen have noticed that with a badly clinkered fire air came up only around the edges of the clinker and of the firebox, and when the grates were moved ash was only shaken

down at these points, while on top of the big clinkers the condition would be unchanged. The slashbar and dump rate is the only remedy for this kind of a fire.

Q. 40. Why does a full, or nearly full ashpan injure combustion?

A. By shutting off the air admission. Ordinarily the back damper will supply all the air needed for combustion, but when the fire becomes heavy or the ashpan filled, both will be needed.

Q. 41. How often should grates be moved?

A. This is a matter largely born of practical experience and good judgment. The only loss that can come to the coke of the coal is by being shaken into the ashpan, unburned, or by the exhaust tearing the fire and carrying pieces of coke unburned through the tubes. Ordinarily coke waits to be burned, while the gas, like time, waits on no man or fire.

Q. 42. What are the effects on combustion of a hole in the fire?

A. An in-rush of air is permitted at that point, which cools the fire and the gases below the igniting point. A loss of heat is a loss of fuel. A hole in the fire is more injurious to combustion than a dead place in the fire that is covered with ash. A fire thick enough to withstand the exhaust, and thin enough so that the light from it shines into the ashpan, may be considered a first-class fire.

Q. 43. What are the effects of fresh coal on fire?

A. To cool it. Then the coal commences to break down and give off gas with which the oxygen mixes, and it is consumed. The thinner the coal is scattered the quicker this process takes place. The amount of coal must at all times be proportioned to the work being done. The fireman who keeps a clean, light fire all the way over the

road will have steam at all times and with less physical fatigue than the fireman who, to avoid hoeing a pan or cleaning a fire, allows his ashpan to fill up and his fire to become heavy.

Q. 44. What are the effects of allowing a fire to burn too low?

A. The gases formed when fresh coal is thrown in will escape unburned on account of the low temperature in the firebox, and a great loss of heat will result, as well as a loss in steam pressure, which is injurious to the firebox and boiler. This practice also spoils a fire.

Q. 45. What are some of the aids to proper combustion?

A. The most important aid is a good, observant fireman, for without him all the other aids fail. No matter what devices are adopted and put in use they must be handled intelligently by the man with the shovel to secure success. The fireman alone can keep his fire in good shape, can shovel the right amount of coal at the right time and handle his dampers and grates so as to secure the best results, and he can only do this by study and observation, and application of the knowledge he thus gains to the best advantage Next to the fireman is the air admission to the firebox.

Q. 46. How is the air admission hastened?

A. By the aid of the exhaust steam forced out of the nozzles up the stack. It is evident that natural draft could not supply the amount of air necessary to a fire when an engine is working, so some device must be used to accelerate the air admission to burn sufficient coal to meet the demand.

Q. 47. How is the exhaust steam made to act as a blast on the fire?

. The tips of the nozzles being smaller than the base
ing, the steam escapes with a greater or less degree
orce, according to the restriction, which must not be
reat as to cause back pressure in the cylinders by not
ving the exhaust steam to escape quick enough. The
nt rush of the steam up the stack creates a vacuum
e smokebox and, at the same time, draws heavily on
irebox to fill the vacuum thus created, which in turn
s on the atmosphere through the medium of the ash-
and dampers. A coal of a hard nature requires a
per exhaust than a softer one that is more easily
en down. When different grades of coal are burned
e same locomotive it is plain that the nozzle must be
sted to burn the harder coal, so that when the softer
is used there will be a waste of fuel. The harder
es of bituminous coal are of a poorer quality than the
r ones. A diaphragm plate is placed in the front end
flect the cinders and aid in regulating the draft, and
tticoat pipe is placed over the nozzle standpipe to
the exhaust straight up the stack, for should it be
cted against one side or the other of the stack the
t is to partially destroy the vacuum in the front end
injure the draft.

48. What does the degree of heat in a locomotive
ebox indicate?

That there is a great loss of heat which should
tilized to make steam, instead of being wasted, but
eans has yet been found that could do this. Modern
ox construction has done much to care for the waste
eat over that of the old style fireboxes, but there is
to be accomplished yet along that line. The velocity
e gases through the tubes tends to cause a loss, as
is no time in their passage through them for the
to be absorbed.

Q. 49. How should air be admitted over the grate area?

A. Equally over the grate surface. If the front-end arrangement is such as to draw air heavily through the grates at one point and lightly or not at all at another, the result is disastrous to combustion.

Q. 50. What is the draft dependent upon?

A. The condition of the fire, ashpan, grates and dampers, the size of the nozzles, and strength of the exhaust, which in turn is dependent on the point of cut-off and the steam admission.

Q. 51. Is sufficient air admission as necessary to thorough combustion as a sufficient supply of coal on the fire?

A. It is.

Q. 52. Is the proper mixing of the air and coal gas important?

A. Yes. The oxygen must come in contact with the gas to be burned at the right time and place.

Q. 53. What aid is placed in fireboxes for the mixing of the coal gas and the air?

A. The brick arch.

Q. 54. What is it?

A. A table of firebrick extending across the firebox from side sheet to side sheet, higher in the center than at the sides, and sloping upward toward the rear of the box and extending back from the flue sheet from one-half to two-thirds the distance to the back sheet. There is a circular opening between the front end of the arch and the flue sheet. The size of the arch depends on the style of firebox and the quality of coal used, and often with the ideas of the master mechanic in charge.

Q. 55. How does the brick arch aid in mixing the gases of the coal and air?

A. By retarding the escape of the coal gases and throwing them back, giving more time for the mixing of the air with them and for their burning. The arch is also very hot when the engine is working, and it aids in keeping the temperature of the firebox up and in burning the gases.

Q. 56. Is the arch of any other benefit to the locomotive than this?

A. Yes. Long after the fire is out the arch, which was red hot when the fire was removed, holds its heat and allows the flues and firebox to cool down slowly and thus tends to keep them from leaking.

Q. 57. What objections are there to the brick arch?

A. Where the flues are leaking it is hard to do work on them unless the arch is removed, and often this takes too much time, and where an engine's flues are poor it can not be done every trip.

Q. 58. How does the interior of the firebox appear when combustion is rapid?

A. Like a small storm center. The rapid in-rush of the air, the quick formation and burning of the gases, which is really a series of miniature explosions, and the exhaust pulling powerfully on the burning gases, which in their rush to escape are hurled back by the arch to be consumed or escape through the stack, are all the work of an instant. The chemical change of a pound of coal and its equivalent of air is almost too rapid for comprehension, when one considers the amount consumed in a short period of time.

Q. 59. What effect has a damp atmosphere or too much water on the coal, or combustion?

A. It retards it, as this moisture must be absorbed and it takes heat to absorb it.

Q. 60. What is the most important question in connection with combustion, to railroads?

A. Economy of fuel consumption. The fuel cost is one of the greatest expenses railroads have to bear in their operation, and it is but natural they should seek relief by using the best appliances available and desiring their intelligent use. There is still much improvement left yet to be desired for some one in the future to attain, before anything like perfect combustion can be secured.

CATECHISM ON FRONT ENDS.

Question 1. What is the thing most to be desired in designing a front end arrangement for a locomotive?

Answer. A design that will give the best possible result in the way of draft.

Q. 2. What is meant by the term, the best possible result?

A. It means the greatest possible amount of steam that can be produced from the smallest possible amount of coal consumed to perform a given work in a given time.

Q. 3. Is a fierce blast on the fire any indication of the best possible draft?

A. No! The fierce blast on the fire is usually brought about by a small nozzle, put in to overcome some other shortcoming of the draft arrangement, and causes the engine to consume more coal than it should to do its work, if it had a proper arrangement of the front end. The small stand-pipe tips are also very frequently the cause of back pressure in the cylinders, as the avenues of escape for the exhaust steam are too small.

Q. 4. How should the inflow of air through the grates and the outflow of air through the flues be distributed?

A. As equally over their surfaces as possible. Any front end arrangement that draws a greater amount of air through grates at any given point or through any certain number of flues is defective, and it will do injury to the tubes and firebox, and, in addition, it is a coal-wasting device.

Q. 5. How is the draft on the fire produced?

A. By creating a vacuum in the smoke arch. The front end that will produce the greatest amount of vacuum in the smokebox and, at the same time, give a uniform distribution of air through the grates and flues without causing back pressure in the cylinders, is the one to be desired.

Q. 6. What form of front end arrangement was formerly most used?

A. What is known as the short front end with a diamond stack. This stack contained a large cone for the purpose of breaking up and deadening the cinders. The top of the stack contained a netting to still further reduce the cinders and lessen the danger from fires. A petticoat pipe, that was adjusted to a certain height above the nozzle tips at the bottom and below the base of the stack at the top, controlled the draft. The smokebox was usually made the same length as the cylinders.

Q. 7. What led to a change in the form of front end arrangement?

A. The smoke and cinders thrown out of the stack were very disagreeable to passengers, the cone braces would burn off, and the inside barrel of the stack would burn out, as well as the netting, and this made the danger of fires greater.

Q. 8. To what did experiments in front end arrangement then lead?

A. To what is known as the extension front end.

Q. 9. Describe it.

A. An extension was added to the front of the smoke arch, of equal or about equal length of the short front end smokebox. This extension was intended to hold the sparks until they could be dumped out, at some designated

point where the engine stopped, through a hopper on the bottom of the smoke arch. A peep-hole plate was put on the side of the smoke arch so the condition of the smokebox could be seen from without.

Q. 10. What was used in the place of the cone in this type of front end?

A. A deflector, or baffle plate, and a netting in the front end below the base of the smokestack. A certain amount of cinders were thrown, and even at the commencement of a trip, with the front end clean, and if the front end was arranged so that cinders could not be thrown out at all, the engines would not steam and the front end would fill up in a few miles and require frequent cleaning out. Gradually these front ends were modified until they would go over the road without being cleaned out. So that after a certain amount of cinders lodged in the front end they were virtually self-cleaning. This style of front end was supposed to lessen the danger of fire over the short front end.

Q. 11. What objections were found to this style of front end arrangement?

A. Fires were still set out. The front ends filled up and burned the smoke-arch so that it cracked and leaked air, destroying the front end vacuum. Peep-hole plates leaked and frequently became lost and cinder hoppers burned out and leaked and were hard to keep in good condition.

Q. 12. What conclusion did locomotive men come to?

A. That if a locomotive front end cleaned itself out nearly all the way over the road it might as well do it all the way and unnecessary equipment be done away with, and the whole front end arrangement be thereby bettered.

Q. 13. What causes a partial vacuum in the front end when engine is working?

A. The exhaust steam from the cylinders escaping through the stand-pipe and passing up out of the smoke-stack. By reason of the force with which it escapes it draws a part of the contents of the front end along with it.

Q. 14. How is this vacuum refilled?

A. By air rushing in through the dampers, grates and flues to the front end and carrying with it a certain portion of the contents of the firebox. As the exhausts come so rapidly as to be in a measure continuous where the engine is moving at any speed at all, it will readily be seen that the air passing through the grates to the front end is really a continuous current moving with a high velocity. This fans the fire into a fierce flame.

Q. 15. Why does a leak about the smoke arch destroy the vacuum in the front end?

A. Because the air coming in at that point fills the vacuum in the smokebox and diminishes the rush of air through the grates. This injures the draft and also the steaming qualities of the engine.

Q. 16. Would the elimination of the spark arresting device in the front end aid in making an engine steam more freely?

A. Yes. Because it would give better draft through the fire.

Q. 17. With what is the partial vacuum in the front end commensurate?

A. The frequency and force of the exhaust.

Q. 18. What effect has the blower when in use, or the air-pump exhaust when in the smoke arch, on the front end?

A. The same as the cylinder exhaust, only in a minor degree.

Q. 19. What definition is given this form of draft?

A. Forced draft.

Q. 20. What is the other form of draft?

A. Natural draft.

Q. 21. Define natural draft.

A. It is the tendency that heated air or other gases have to rise, allowing cold air to come in and take their place. This is the form of draft that the locomotive has when standing idle with fire burning and blower and air pump exhaust closed. An engine that steams well under natural draft usually will with forced draft, and it indicates a well-arranged front end.

Q. 22. What regulates the draft with the short front end?

A. The variable arrangement of the petticoat pipe with the nozzles as an auxiliary aid.

Q. 23. What regulates the draft with the extension front end?

A. The baffle, or diaphragm, plate with the nozzles as an auxiliary aid.

Q. 24. Has the coal anything to do with the size of nozzles that may be successfully used?

A. Yes. A soft, easily igniting coal free from dirt and slate will allow the use of larger stand-pipe tips than a harder coal containing more waste material and that ignites more slowly. The larger the nozzle that can be used, the more economical will be the coal consumption.

Q. 25. What would the result be if the baffle plate ran solidly from the top to the bottom of the smoke arch?

A. There would be no communication from firebox to smokebox. Some forms of extension front ends almost

reached this extreme by a roundabout road, and their creators seemed to wonder why their engines did not steam.

Q. 26. What effect has raising the baffle plate from the bottom of the smoke arch?

A. The more it is raised the more free the communication between the firebox and the front end, and the less are the gases and sparks deflected from their direct course of escape.

Q. 27. What effect has the arrangement of the baffle plate on the flues?

A. The lower flues, being opposite the point of the most open communication, are naturally drawn on the hardest and give out more quickly than the others.

Q. 28. To what was this early failure of the bottom flues often charged?

A. To their being in line with the firebox door and receiving the rush of cold air through it when the door was opened in firing.

Q. 29. Did the use of the brick arch overcome this trouble?

A. Not altogether, but it helped. Finally it was evident that about one-third of the tubes were doing three-fourths of the work, and that this result was chargeable to the front end arrangement.

Q. 30. What aided in forming this conclusion?

A. The fact that with very large engines the upper rows of flues would fill up with ashes in a single trip, thereby plainly indicating that the same draft force was not exerted on these tubes as on the lower ones, else they would be in a similar condition.

Q. 31. In making a change from the extension front end to the self-cleaning front end, what questions confronted master mechanics?

A. Whether it would be more economical in the matter of coal saving; if a saving could be made in flues and the general care of the firebox; if the cinders thrown out by the self-cleaning front end would be no more disagreeable to the traveling public, and if they would involve no more danger of fire. The latter seems to have been the verdict after a fair trial, for the self-cleaning front ends are coming into very general use.

Q. 32. What can be dispensed with in the self-cleaning front end that was a necessary part of the extension front end?

A. All that portion of the front end used to contain cinders, the cinder hopper and the peep-hole plate.

Q. 33. Does the short stack on the big engine give as good steaming results as the long stack?

A. No. It does not.

Q. 34. How is this in a measure overcome?

A. By the use of a suitable petticoat pipe. Some roads have tried using an extension of the stack down into the smokebox.

Q. 35. Has this proven on the whole to be a satisfactory device?

A. It has not. It causes the smoke and gases to back up, as there is no opening to the stack at the bottom of the smoke arch; this destroys the natural draft of the engine, and the smoke and gases coming out in the cab when the engine is not working steam make it very disagreeable for the men in the cab.

Q. 36. Has the effort to dispense with petticoat pipes been a success?

A. No. For the following reasons: The locomotive requires smaller nozzles, and therefore uses more coal and is more liable to back pressure. The locomotive will

make steam more slowly when fired up and the blower will not be so effective when an attempt is made to force the draft. The exhaust steam becomes scattered and does not pass directly from the stand-pipes and the stack as it should to create the best draft.

Q. 37. What should limit the length of the smoke arch?

A. The area of the netting desired.

Q. 38. Is there any difference appreciable in the use of the single or double nozzle?

A. Apparently not. Those using either type seem to consider that particular kind the best. The height of the nozzle in conjunction with the petticoat pipe seems to be of greater importance than the mere fact that the nozzle is single or double. The short nozzle is to be used with the long petticoat pipe and vice versa.

Q. 39. How can the draft be changed with the baffle plate?

A. An overlap plate is used at the bottom of the diaphragm plate. This plate can be raised or lowered at will, so as to change the opening at the bottom of the smoke arch and thereby give a more open draft space.

Q. 40. Why is the baffle plate a disadvantage to the locomotive in a certain way?

A. Because the smoke and gases, coming almost instantly in contact with it when they leave the flues, are deflected from their true course before being allowed to escape. Hence the name deflector or baffle plate.

Q. 41. What care should be taken in placing a baffle plate?

A. It should be placed so that it will not be too close to the flue sheet, and angled away from it so that the sparks and gases will not be deflected too sharply down-

ward. An engine with the baffle plate too near parallel with the flue sheet would not be a good steamer.

Q. 42. If nozzle tips were extended above the base of the stack, what would be the result?

A. The required vacuum would not be produced in the front end and deficient draft would result. The nozzle tips must be enough below the base of the stack to draw on the contents of the smoke arch. It would seem, therefore, that the petticoat pipe will remain for some time, at least, as a part of the smoke arch equipment.

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DIFFERENT PARTS OF A LOCOMOTIVE

ALPHABETICALLY ARRANGED.

Firemen and others should learn the names and uses of the various parts of a locomotive.

Students preparing for examinations will find such knowledge indispensable.

The 254 parts shown in the accompanying folder-plate (Fig. 54) of an eight-wheel locomotive, are arranged as follows in alphabetical order, a reference number being given by which any part may be quickly found.

A

Air Bellringer 133
Air Brake Hose........... 5
Air Cylinder Brake Pump.169
Air Drum 99
Air Drum Bracket......... 98
Air Gauge 207
Air Pipe to Bellringer....247
Air Pipe to Governor.....248
Air Pump Exhaust Pipe... 29
Air Pump Lubricator......206
Air Pump Throttle........214
Air Signal Hose........... 4
Air Signal Pipe............ 88
Air Strainer 171
Arch Brace 10
Arch Hand Rail........... 39
Ash Pan 139
Ash Pan Dumper Handle..228

B

Back Crank Pin...........253
Back Cylinder Head....... 58
Back Up Eccentric.........159
Back Up Eccentric Rod....162
Back Up Eccentric Strap...163
Balance Plate 46
Balance Slide Valve....... 47
Bell 132
Bell Ringer Valve.........246
Bell Stand 131
Blower 30
Blower Cock...............211
Boiler Jacket 127
Boiler Lagging 126
Brake Valve Reservoir.....230
Branch Pipe...............119
Bridges 53
Buffer Beam............... 7

C

D

E

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

V

W

LOCOMOTIVE TRACTION AND ADHESION.

ADHESION PER TON OF LOAD ON THE DRIVING WHEELS.

When the rails are very dry...........600 lbs. per ton.
When the rails are very wet...........550 lbs. per ton.
In misty weather if the rails are greasy..300 lbs. per ton.
In frosty or snowy weather............200 lbs. per ton.

In coupling engines the adhesive force is due to the load on all wheels coupled to the driving wheels.

The adhesive power must exceed the tractive force of an engine on the rails, otherwise the wheels will slip. For loads on driving wheels, see the following:

DISTRIBUTION OF WEIGHT IN LOCOMOTIVES.

The average distribution of the weight of a six-wheeled locomotive on its wheels is:

Assuming the total weight of the engine working order to be 1:

	Passenger Engines.	Freight Engines.
Load on leading wheels...........	.32	.34
Load on driving wheels...........	.48	.36
Load on trailing wheels...........	.20	.30
Total weight of engine........	1.00	1.00

TO FIND THE LOAD WHICH AN ENGINE WILL TAKE ON A GIVEN INCLINE.

Let G = Resistance due to gravity on the steepest gradient in lbs. per ton.

Let R = Resistance due to assumed velocity of train in lbs. per ton.

Let T = Tractive power of engine in lbs., as found above.

Let W = Weight of engine and tender in tons.

The load the engine can take in tons, including the weight of the cars, but not that of engine and tender will equal $\frac{T}{G+R} = W$.

NUMBER OF REVOLUTIONS AT DIFFERENT SPEEDS.

This table gives the number of revolutions that are made by the driving wheels of different sizes, (from 4 feet to 7 feet in diameter), per minute, at different speeds, from 5 to 60 miles per hour:

Diameter of Driving Wheels.		Speed per Hour in Miles.											
		5	10	15	20	25	30	35	40	45	50	55	60
		Revolutions per Minute,											
Feet.	Inches.												
4	0	35	70	105	140	175	210	245	280	315	350	365	420
4	3	33	66	99	132	165	194	231	264	297	330	362	395
4	6	31	62	93	124	156	186	217	249	280	311	342	373
4	9	29½	59	88	118	147	177	203	236	265	295	324	354
5	0	28	56	84	112	140	168	196	224	252	280	308	336
5	3	26⅔	53	80	107	133	160	187	213	240	267	293	320
5	6	25½	51	76	102	127	153	178	204	229	255	280	306
5	9	24⅓	48	73	97	122	146	170	195	219	243	267	292
6	0	23⅓	46	70	93	117	140	163	186	210	233	255	280
6	3	22½	45	67	89	112	134	156	178	201	223	244	268
6	6	21½	43	64	86	108	129	151	172	194	216	237	259
6	9	20¼	40	61	81	101	121	142	164	182	202	223	243
7	0	20	40	60	80	100	120	140	160	180	200	220	240

SECONDS PER MILE IN MILES PER HOUR.

Seconds per Mile	Miles per Hour	Seconds per Mile	Miles per Hour
24	150	58	62
25	144	59	61
26	138.5	60	60
27	133.3	61	59
28	128.5	62	58
29	124.1	63	57.1
30	120	64	56.2
31	116.1	65	55.3
32	112.5	66	54.5
33	109	67	53.7
34	105.8	68	52.9
35	102.8	69	52.1
36	100	70	51.4
37	97.3	71	50.7
38	94.7	72	50
39	92.3	73	49.3
40	90	74	48.6
41	87.8	75	48
42	85.7	76	47.3
43	83.7	77	46.7
44	81.8	78	46.1
45	80	79	45.5
46	78.2	80	45
47	76.6	81	44.4
48	75	82	43.9
49	73.4	83	43.3
50	72	84	42.8
51	70.5	85	42.3
52	69.2	86	41.8
53	67.9	87	41.3
54	66.6	88	40.9
55	65.4	89	40.4
56	64.3	90	40
57	63.1		

TO FIGURE WHAT A LOCOMOTIVE WILL PULL.

With the engine adjusted to steam freely, a valve motion that will insure a good steam distribution and the machine properly lubricated, the next problem is the capacity of the engine to move tons of freight or passenger trains over the road. It costs money to operate a railroad and the revenue is obtained from the sale of transportation. Assuming that the locomotive is of modern design and assigned to the class of service best adapted for, the next point to determine is the draw bar pull or how much tractive power will be developed to overcome the train resistance. First the adhesion or weight placed on the drivers must be greater than the resistance of the train, and this weight is usually limited by the condition of the road bed, weight of rails and strength of bridges. Here is where the engineering department specify to the mechanical officers the number of pounds that may be placed on the driving wheels of the locomotive. The diameter of the driving wheels, diameter of cylinders, length of stroke of the piston in inches and the number of pounds of steam pressure per square inch carried on the boiler, will enable us to determine approximately the tractive power, when the use of a dynamometer car is not available. The tractive power, developed by a single expansion locomotive at slow speed may be ascertained by assuming that 85 per cent of the boiler pressure will equal the mean effective pressure in the cylinders and using the formula:

$$\frac{C^2 \times S \times P}{D} = T$$

Now this is not at all hard and a little time will make this and other formulas easy to figure.

C^2 indicates that the diameter of the cylinder should be multiplied by itself, or squared.

S equals the stroke of the piston in inches.

P—— the mean effective pressure in pounds or 85 per cent of the boiler pressure.

D equals the diameter of the driving wheels in inches and placed under the line means that when the diameter of the cylinder is multiplied by itself or squared, that number multiplied by the number of inches of stroke and then by the number of pounds mean effective pressure, all this above the line should be divided by D or the diameter of the driving wheel in inches, which will give T or the tractive power.

Example: An engine 20x26″ cylinders, 56″ wheels, 200-lb. boiler pressure.

$C^2 = 20 \times 20$		20
		20
$S = 26''$		400
		26
	200	2400
85% of P =	.85	800
	1000	10400
	1600	170
	170.00	728000
		10400
		1768000

Diam. of Driver 56)1768000(31,571 lbs. Trac. Force.

```
168
---
 88
 56
---
 320
 280
 ---
  400
  392
  ---
    80
    56
    --
     4
```

$$T = \frac{C^2 \times S \times P}{D}$$ or 31,571 Pounds—That is

31,571 pounds tractive power developed by the engine that can be used to overcome the resistance of the locomotive and train. This rule is applicable to any size single expansion engine.

For a two-cylinder compound use this formula:

$$\frac{C^2 \times S \times 2\text{-}3\ P}{D} = T.$$

using two-thirds of the boiler pressure and considering the high pressure cylinder only.

Example: What is the tractive power of a two-cylinder compound:

Cyls. $\frac{22}{33}$ x 26″ Drivers 63″ Boiler pressure 210 lbs.

```
            22
            22
            --
            44
           44
        -----
           484
            26
        -----
          2904
          968
        -------
         12584        2-3 of 210 = 140 lbs.
           140
        ------
        503360
       12584
      -------
D=63") 1761760(27,964 Pounds, Tractive Force.
       126
       ---
       501
       441
       ---
        607
        567
        ---
        406
        378
        ---
         280
         252
         ---
          28
```

The tractive power of a four-cylinder compound may be ascertained by the following formula:

$$\frac{C^2 \times S \times 2\text{-}3\ P}{D} + \frac{C^2 \times S \times \frac{1}{4}\ P}{D} = T$$

Work this out separately for the high and the low-pressure cylinders the same as was done for the simple and add the quotients.

Example: What is the tractive power of a four-cylinder compound:

Cyls. $\frac{15}{25}$ x 26″ Drivers 73″ Boiler Pressure 220 lbs.

High Pressure cylinder.

```
             15
             15
             --
             75
            15
            ---
            225
             26
           ----
           1350
           450
           ----
           5850
2-3 of 220 = 146
          -----
          35100
         23400
         5850
         ------
         854100
```

```
73 ) 854100 ( 11,700
      73
     ----
      124
       73
      ----
       511
       511
      ----
        00
```

Low Pressure Cylinder.

```
                  25
                  25
                 ----
                 125
                 50
                 ----
                 625
                  26
                ----
                3750
               1250
               -----
               16250
¼ of 220 =        55
               -----
               81250
              81250
              -----
      73 ) 893750 ( 12,243
           73
           ---
           163
           146
           ---
```

```
 177
 146
 ---
 315
 292
 ---
  230
  219
  ---
   11
```

11,700+12,243=23,943T.

TRAIN RESISTANCE OR LOCOMOTIVE RATING.

To overcome the resistance of one ton, 2,000 lbs., on a straight and level track at a speed of ten miles per hour or less, careful tests have demonstrated that it varies from 5 to 8 lbs. per ton, or an average of 6½ lbs. per ton. It is safe to allow 8 lbs. per ton for train resistance on a level, and by dividing the tractive power by 8 it would give the number of tons rating. This rule covers the axle or journal and rolling friction only. If on a grade, multiplying the feet per mile rise in grade by .3788 will give the resistance due to grade per ton and will be sufficiently correct to establish a rating in the absence of a regular test or a dynamometer car; or if preferred, add ⅜ lbs.= to .375 per ton for each foot per mile rise in the grade. Either of the above decimals will answer for grade resistance. Curve resistance may be figures as 9.16 lbs. per ton for every degree of curve, 9.16=.5625. Using this decimal and multiplying by the number of degrees in the curve we get the curve resistance.

Example: What is the resistance per ton of train on a grade of 100 feet per mile with 4 degree curve.

Allowing 8 lbs. for friction.
$100 \times .375 = 37.5$ lbs. for grade.
$4 \times .5625 = 2.25$ lbs. for curve.

$$47.75$$

we have 47.75 lbs. resistance per ton.

These figures are not given as absolutely correct in establishing a rating, but will serve to work from in making up trains for test. The only correct method to rate an engine is to take several engines of the same class and make actual tests in service to get the hauling capacity, then reduce the tonnage of train to meet the requirements of the service and leave a sufficient margin of power to insure proper time being made under average conditions. The old method of "the last car she will pull" lost out long ago, and the most economical rating at the present time is a train that can be handled and gotten over the road, without tying up opposing or following trains.

SHORTCUTS FOR FIGURING RESULTS.

To find the circumference of a circle multiply its diameter by 3.1416.

To find the diameter of a circle multiply its circumference by .31831.

To find the area of a circle multiply the square of its diameter by .7854.

To find the cubic inches in a ball multiply its cube of diameter by .5236.

To find the revolutions of drivers per mile divide 1680 by the diameter of the wheel in feet.

To find the revolutions per minute multiply the speed in miles per hour by 28 and divide the product by the diameter of the driving wheel in feet.

To find piston speed in feet per minute multiply revolutions per minute by twice the stroke of piston in feet.

To find the speed of train per second multiply speed in miles per hour by 22 and divide by 15.

To find time when rate of speed and distance is given multiply distance by 60 and divide by rate of speed.

To find rate of speed when distance and time are given multiply distance by 60 and divide by the time in minutes.

To find the distance when the time and rate of speed are given, multiply the time by the rate of speed and divide by 60.

To find the number of tons of coal in a bin: Length, height and width of pile in feet multiplied together, divide by 30 for hard coal, by 35 for soft coal, by 128 for cords of long wood, and by 135 for cords of sawed wood.

To find the pounds of coal used per 100-ton mile multiply pounds of coal by 100 and divide by tons multiplied by the miles hauled.

To find the pressure in pounds per square inch of a column of water multiply the height of the column in feet by .434.

HYDRAULICS.

A gallon of water (U. S. standard) weighs 8 1-3 lbs., and contains 231 cubic inches.

A cubic foot of water weighs 62½ lbs., and contains 1,728 cubic inches, or 7½ gallons.

Doubling the diameter of a pipe increases the capacity four times.

Each nominal horse power of boilers requires 1 cubic foot of water per hour.

In calculating horse power of steam boilers, consider for Tubular boilers 15 square feet of heating surface equivalent to 1 horse power; Flue boilers 12 square feet of heating surface equivalent to 1 horse power, and Cylinder boilers 10 square feet of heating surface equivalent to 1 horse power.

To find the area of a piston, square the diameter and multiply by .7854.

To find the pressure in pounds per square inch of a column of water multiply the height of the column in feet by .434. (Approximately we generally call every foot elevation equal to ½ lb. pressure per square inch.)

To find the capacity of a cylinder in gallons. Multiplying the area in inches by the length of stroke in inches will give the total number of cubic inches; divide this amount by 231 (which is the cubical contents of a gallon in inches), and product is the capacity in gallons.

*CATECHISM ON LOCOMOTIVE TRACTION AND ADHESION.

Question 1. What is a locomotive?

Answer. A horizontal boiler with two high pressure engines and accessories attached to a frame, the whole mounted on wheels and designed to move on two parallel rails.

Q. 2. What is a locomotive commonly termed?

A. An engine, although a locomotive has two engines that are dependent on each other for the perfect performance of the locomotive, but which, in case of the failure of one engine the other may be used independently but with a great loss of power to the machine. When both engines are in perfect condition one engine is exerting its greatest power at the point where the other one is practically useless as a power-exerting medium. This condition is, of course, reciprocal.

Q. 3. Can a train be handled with one side of locomotive disabled?

A. That depends on the physical characteristics of the road and the nature of the disablement of the engine, as well as the class of locomotive to which the injury occurs. With the lighter class of locomotives and level roadbed, with side rods up 50 per cent. or better of a train can be handled, but with an unfavorable grade or with side rods down the engine will do no more than to handle itself. The heavy modern locomotive will do no more than handle itself without side rods up, as with only one pair of drivers to furnish the adhesion to pro-

*W. L. French.

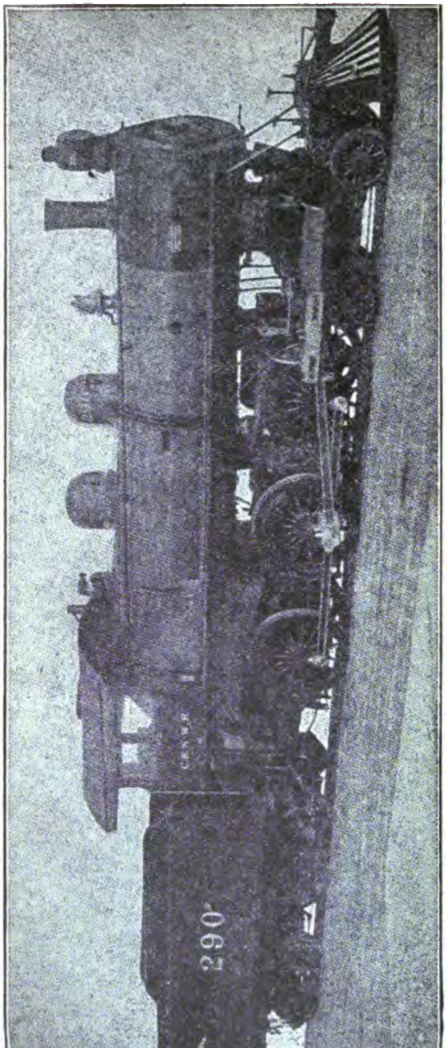

Figure 55. A Ten-Wheel Freight Locomotive.

pel the whole weight of the locomotive it will stand and slip and will not handle itself to a terminal.

Q. 4. How do the engines of a locomotive transmit their power to the driving wheels?

A. The power exerted by the steam pressure on the piston head is transmitted by medium of the piston rod, crosshead, wrist pin and main rod to the crank pin which is located on the outside of the driving wheel between the hub and the outer edge of the wheel. This arrangement makes a crank lever of the pin and gives a rotary motion to the wheels, propelling the locomotive and its load in the direction indicated by the position of the reverse lever.

Q. 5. What is meant by the term slipping?

A. It is the spinning around on the rails of the driving wheels without advancement other than that gained by previous momentum of the locomotive and its load.

Q. 6. Is it injurious to a locomotive, and if so, why?

A. It is, from the fact that the driving wheels and rods, together with the other machinery dependent on them for the regular and even movement of the locomotive, are turned loose at an unusually rapid rate without any check on their momentum except such as the strength of the material can offer, and with a straining effect upon it.

Q. 7. What effect has driving wheels slipping on the rail?

A. If the engine is just starting and slips many turns, a small flat spot will be found on the top of the rails.

Q. 8. When is there the greatest danger of damage to the machinery from an engine slipping, when running at a high or low rate of speed?

A. At a low rate of speed, because at a high rate of

speed the revolutions of the wheels are not increased so much over normal as when slipping at a low rate of speed.

Q. 9. What is used to avoid or overcome driving wheels slipping?

A. Sand.

Q. 10. Should steam always be shut off from cylinders before sand is applied to rails?

A. Yes, in all cases. If engine is slipping, the sudden catching of. wheels is liable to result in the loss of a crank pin or other damage, besides subjecting it in any event to an unnecessary strain.

Q. 11. What effect has the use of sand?

A. To increase the adhesion of the driving wheels and the friction of the train wheels.

Q. 12. Upon what is the power of a locomotive to do work dependent?

A. On the energy it can exert to produce motion without the driving wheels slipping, and is dependent on the adhesive power of the locomotive. This power is proportional to the weight on the driving wheels.

Q. 13. What is adhesion?

A. The property which the wheels have of clinging to the rails.

Q. 14. How may adhesion be increased or diminished?

A. Increased by the use of sand, which makes the friction greater, and lessened by a wet or frosty rail, which reduces the friction. Sand on a wet rail will give about the same adhesion that a dry rail would have without the use of sand. If the sand lever is opened wide and two heavy streams of sand are run on the rail, friction will be greatly increased on the train wheels and a

train "stalled" that could have been pulled with a lighter use of sand, besides exhausting the supply sooner than necessary, which is limited to the none too great capacity of the sand box.

The frequent opening and closing of the sand valves will give the best results on a hard pull, for if the valves are left open just a little to run fine streams of sand they will speedily close up and the wheels will slip. The quantity of sand that will give the requisite adhesion with the least train friction is what is desired.

Q. 15. What devise is used to accomplish this result?

A. The air sander.

Q. 16. Describe it.

A. A sand pocket is attached to the outside of the sand box at the bottom, with an air nozzle enclosed for each sand pipe. The sand comes through a clear passage from the sand box. This form of sander permits the use of a sand lever also, if desired. The air to operate the sander is taken from the main air reservoir and is carried to the sander through a small pipe that is sometimes placed underneath and sometimes outside of the boiler jacket. A globe valve admits the air from the main reservoir to this pipe. The thread of this valve stem is very fine, so that several turns of the wheel must be taken to use the sander heavily and a heavy stream of sand from a sander would be only a light stream with a lever. The valve seat of the globe valve is nearly parallel with the valve, and this aids in its fine adjustments and prevents a waste of air.

Q. 17. What is the use of the blow port in the handle of the air sander?

A. To give warning that the air sander is open, otherwise it might be left open longer than desired, causing a waste of both air and sand.

Q. 18. How much of the driving wheel tire rests on the rail?

A. About the width of a line.

Q. 19. Should the use of sand on one side be avoided?

A. Yes, as the strain of both engines is thrown on one side. Should the wheels slip and catch, there is greater likelihood of damage.

Q. 20. Is there anything aside from a "bad" rail that will cause wheels to slip?

A. Yes. Too great cylinder power for the adhesion of the wheels. This condition is not intended to exist. A small driving wheel will slip with the same cylinder power more easily than a larger wheel because greater leverage is exerted.

Q. 21. What part of a locomotive's weight is available for adhesive weight?

A. About 75 per cent. of its total weight, although some recently built locomotives have as high as 88 per cent. of their weight on the driving wheels.

Q. 22. Why is it not possible to put all the locomotive's weight on the driving wheels?

A. Because it would increase the rigid wheel base to an unsafe degree, as the engine would not "curve" readily and safely, and it is therefore necessary to carry a portion of the locomotive's weight on engine trucks that are used as a guide for the locomotive.

Q. 23. What is tractive power in a locomotive?

A. Its power to pull. It is always less than adhesive power.

Q. 24. On what is the tractive power dependent?

A. The length of the stroke, area of piston, average mean effective steam pressure and diameter of driving wheels.

Q. 25. How can the amount of tractive force exerted by a locomotive for each revolution of the driving wheel be determined?

A. Suppose the cylinders to be 20x28 inches. Find area of the piston by multiplying the square of the diameter by the fixed decimal .7854. While this decimal number is not perfectly exact, it is enough so for all practical purposes. Then $(20^2=400)$x$.7854=314.16$ square inches. This multiplied by the average steam pressure, which for convenience we will place at 100 pounds per square inch, gives 31,416 pounds pressure on the piston. Each piston must travel the length of the cylinder and return for each revolution of the driving wheels, and as there are two pistons we have this power exerted through four times the length of the stroke, or 4x$28=112$ inches, or 9.33 feet. Then $31{,}416\times9.33=293{,}111+$ foot pounds of energy exerted to move the locomotive and its load through each revolution of its driving wheels.

Q. 26. How can the amount of pressure exerted through each foot the locomotive advances be determined?

A. If the driving wheels are 4.5 feet in diameter, multiply the diameter by the fixed decimal 3.1416, which will give 14.137 feet as the circumference of the driving wheels. The total pressure exerted for one revolution of the driving wheels $= 293{,}111 \div$ the circumference 14.137 feet $=$ 20.734 pounds, the energy exerted for each foot the locomotive advances.

Q. 27. How is the tractive power of a locomotive increased or diminished by changing the size of the driving wheels?

A. Inversely. That is, as the size of the wheel is decreased the tractive power increases, and vice versa.

Q. 28. What is the reason for the increase of power with a small driving wheel?

A. Because the fulcrum of the lever and point of application are brought nearer together without shortening the lever. It is a well known fact that in the use of a lever, the shorter the distance between the fulcrum and the point of contact (or bite, as it is often called), can be and still be effective, the greater the force exerted with the same length of lever and the more easily can the object worked on be moved. On a small driving wheel the lever or crank can not go beyond a certain length or the rod end connections will strike the ties. The real tractive power of a locomotive is the difference obtained through the agency of the crank pin over the pressure exerted against the piston head in one direction and the cylinder head in the other.

Q. 29. What has a locomotive to overcome in propelling a train?

A. Its own inertia, the inertia of its load and the friction of both.

Q. 30. How is train friction increased?

A. By too free use of sand and dry journal bearings.

Q. 31. How is engine friction increased?

A. By deficient lubrication. This does not amount to so much except in case of the valves, where it is very noticeable, especially in the case of high-pressure engines.

Q. 32. What is true then in regard to adhesive and tractive power?

A. That adhesion depends on the weight resting on the drivers, which is from 75 to 88 per cent. of the whole

weight of the locomotive, and the condition of the rail, and that adhesion may be increased by the judicious use of sand without injury to tractive power. That tractive power is less than the adhesive power of the locomotive and is dependent on size of driving wheels, length of stroke, size of cylinder (or piston) and average mean effective steam pressure.

*THE LOCOMOTIVE BOILER.

"The boiler shell in longitudinal section, partial cross-section, and partial end view, shown in Fig. 56, is adapted for burning bituminous coal. The principal parts are the *firebox A,* the *boiler barrel* or *waist B,* the *smokebox C,* the *extension front C,* the *smokestack D,* and the *steam dome E.*

"The firebox is the part of the boiler which is varied for the different fuels; for bituminous coal, according to the quality, the depth of the fire is from 16" to 24", and the firebox must be built deep enough for the combustion. Since it requires but a small grate area, it is possible to place the fire-box between the two driving axles. For anthracite the fire-box is larger in size than for soft coal, because a shallower fire is necessary, ranging from 5" up to 17" in depth; therefore a larger grate surface is required for combustion than in those boilers burning bituminous coal.

"The fire-box is composed of the outside shell *a* and the inside shell *b,* the space between them being filled with water, except the upper part, which is only partly filled with water, the remaining space being filled with steam. The upper part *c* of the inside shell is called the *crown sheet,* and is usually flat, as shown in the cross-section. *F* is the *door,* or furnace opening, through which the fuel is thrown on the grate. The *mud ring k* closes the opening between the inner and outer shells.

"At *h* is shown one of the handholes, or mud-holes,

---

*Civil Engineering, Inter. Text Book Co.

used for cleaning out the water space; *q*, on the extension front, is the cleaning door.

"Owing to the extremely high pressure carried by locomotive boilers, sometimes as high as 200 lb. per sq. in., the flat surfaces would bulge out if unsupported; to prevent this they are braced or stayed by numerous screw stays *v*. These screw stays, or staybolts, as they are often called, are threaded and screwed into the shells, which have been previously drilled and tapped; they are then riveted over at both ends to make them steam tight and secure."

The boiler is the most important part of the locomotive. If it be of improper design, or if it be allowed to get in bad condition, the whole locomotive is lame and inefficient. The boiler is the very soul of the machine. All other parts—cylinders, wheels, valves, etc.—are subsidiary to it. It is the boiler, more than anything else about the locomotive, that determines quality of service and measures economy of operation.

The efficient engineer—and the fireman who hopes to be one—should know his boiler "like a book." He will become more and more the master of his job as he becomes more and more familiar with those "fine points" of design which are too often left wholly unconsidered outside the designer's office and the drafting room in the locomotive works—such as the shape and proportions of the boiler, relation of grate area to heating surface, form of firebox, diameter, length, and spacing of tubes, etc.

The outside sheets of a boiler and the throat sheet are illustrated in figure 57. *1* represents the smoke-box and extension front; *2* the first ring of the boiler; *3* the second ring, or slope sheet if on an incline forming a

wagon top; *4* is the third ring or dome sheet. These parts form the barrel of the boiler. Sheet *5* is the sheet that connects the underside of the barrel of the boiler to

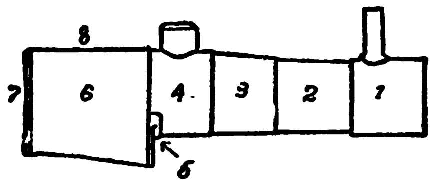

Fig. 57.

the outside shell or firebox and is usually termed the throat sheet; *6* is the outside sheet of the firebox; *7* is the back boiler sheet, or head; and *8* is the roof sheet. The firebox consists of a back sheet, flue sheet, two side sheets and a crown sheet. The front flue sheet is next

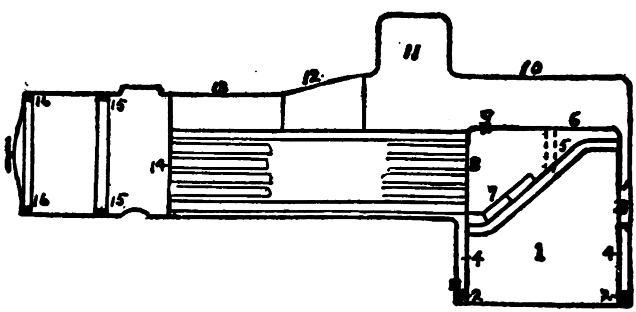

Figure 58. Showing the Parts of a Boiler.

to the smokebox. The lower edges of the inside and outside shells of the firebox are riveted to an iron ring called the "mud ring."

The various parts of a locomotive boiler are indicated in figure 58, each part being numbered to correspond with the proper name of the part as follows:

1 firebox; *2* mud or foundation ring; *3* fire door opening; *4* water space or water leg; *5* brick arch tubes; these either go into back sheet or above, as shown by dotted lines; *6* crown sheet; *7* brick arch, made of fire brick; these become red or white hot and aid combustion of gases; *8* firebox flue sheet or back flue sheet; *9*

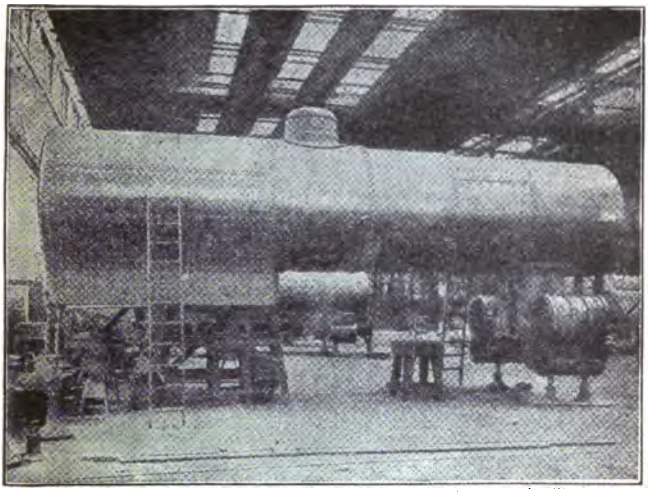

Figure 59. Boiler as Sent to Erecting Shop.
Riveting finished, stay-bolts screwed in, dome mounted, and tube sheets inserted.

fusible plug, made of brass with a soft metal center which melts when the crown sheet becomes dry and allows the steam to flow into the firebox and extinguish the fire; *10* back sheet of outer shell; *11* dome; *12* slope sheet; *13* front sheet; *14* front flue sheet; *15* middle smoke box ring; *16* front smoke box ring. The flues are shown broken in the center, but no one will be in doubt as to the way they look or their proper name.

TO FIND INSIDE DIAMETER OF BOILER.

To find the inside diameter of a locomotive boiler:

RULE.—Multiply the diameter of the cylinder in inches by 2.98; the product will be the diameter of the boiler in inches.

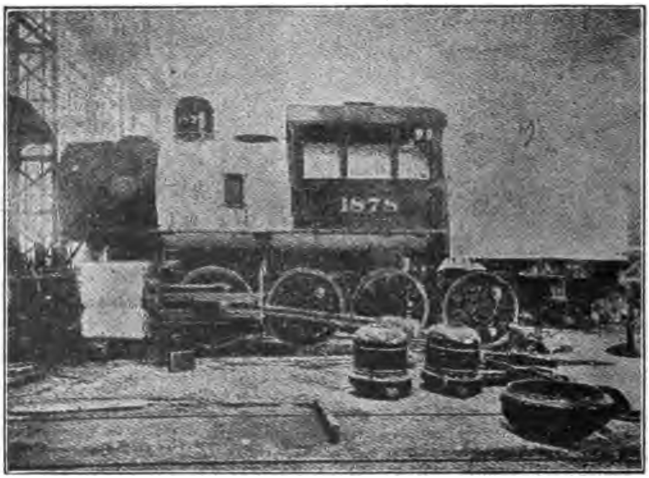

Figure 60. Lagging a Boiler.

Strips of magnesia are used for the purpose, fastened by cleats to wire hoops encircling the shell. Cylinders are lagged with cement. Outside the lagging, is fastened a protective sheet-iron jacket.

AREA OF FIRE GRATE.

To find the area of the fire grate of a locomotive boiler:

RULE.—Multiply the diameter of the cylinder by .87; the product will be the area in square feet.

AREA OF HEATING SURFACE.

To find the area of effective heating surface of a locomotive boiler:

RULE.—Multiply the diameter of the cylinder by its diameter, and multiply the product by 7; divide the last product by 2; the quotient will be the area of effective heating surface, in square feet.

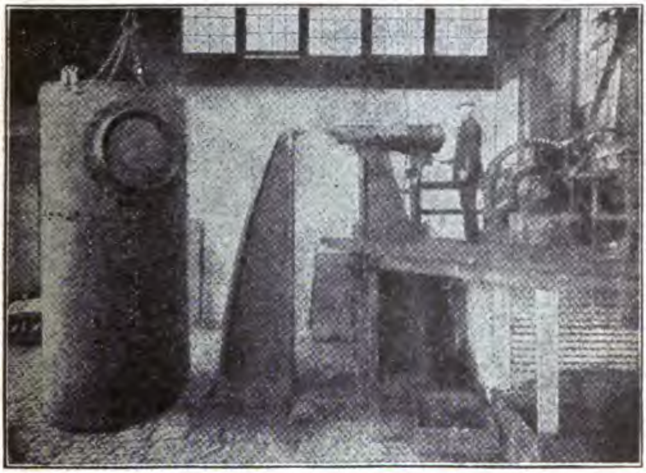

Figure 61. Boiler Riveting Machine.

The boiler shell, suspended by chains from overhead travelers, is raised or lowered as required. The sheets pass between the fixed die, which forms rivet head on inside of shell, and the movable die, which finishes other end of rivet by hydraulic power on the outside.

Example: To find the effective heating surface, the cylinder being 16 inches in diameter: $16 \times 16 = 256 \times 7 = 1{,}792 \div 2 = 896$ square feet.

CUBICAL CONTENTS OF WATER IN A LOCOMOTIVE BOILER.

To find the cubical contents of water in the boiler, when having 3 gauges of water:

RULE.—Multiply the diameter of the cylinder, in inches, by its diameter; multiply the product by 9, and

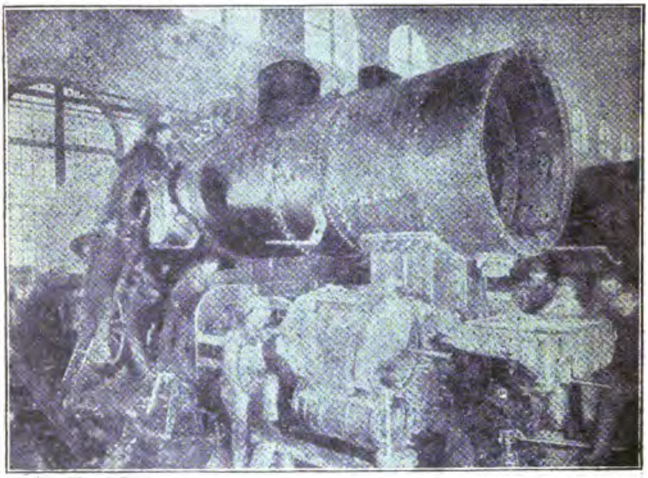

Figure 62. Erecting a Locomotive.

Boiler and cylinders assembled; frames in place; driving wheels in place.

divide the last product by 18; the quotient will be the cubical contents of the water in the boiler, in cubic feet.

Example: To find the cubical contents of water in a boiler of a locomotive, the diameter of cylinder being 16 inches: $16 \times 16 = 256 \times 9 = 2{,}304 \div 18 = 128$ cubic feet of water, or about 960 gallons.

AREA OF EXHAUST PORT.

To find the area of exhaust-port, the exhaust-port is required to be twice the area of the steam-port; the length of exhaust-port will be the same as the steam-port:

RULE.—Multiply the diameter of cylinder, in inches, by its diameter; multiply the product by .148; the product will be the area in square inches.

Example: To find the area of an exhaust-port, the cylinder being 16 inches in diameter: $16 \times 16 = 256 \times .148 = 37.88$ square inches.

AREAS OF SAFETY VALVES.

1¾	2.40	2¾	5.94	3¾	11.04
1⅞	2.76	2⅞	6.49	3⅞	11.76
2	3.14	3	7.07	4	12.57
2⅛	3.55	3⅛	7.67	4⅛	13.36
2¼	3.98	3¼	8.30	4¼	14.19
2⅜	4.43	3⅜	8.95	4⅜	15.03
2½	4.91	3½	6.62	4½	15.90
2⅝	5.42	3⅝	10.32	4⅝	16.80

In multiplying decimal numbers, allow as many places for decimals in the product as there are decimal places in the multiplier and multiplicand together.

In dividing decimal numbers, allow as many places for decimals in the quotient as, taken with those of the divisor, will together make up the number of decimal places in the dividend.

AREA OF CYLINDER.

RULE.—To find the area of a cylinder, multiply the diameter of the cylinder by the diameter in inches, and multiply the product by the decimal .7854; the product will be the area in square inches. The principle of this Rule is that for every imaginable diameter of a circle, if a square be circumscribed around it, the circle will occupy .7854 part of such square.

To get the solid contents of a cylinder, multiply its end area by the combined length of the stroke and clearance in inches; the product will be the capacity of the cylinder in cubic inches, which divided by 1,728 will give the cubic feet.

RULES FOR BOILER FEEDING.

1. Engineers are responsible for the constant maintenance of a safe supply of water in the boiler; also for the observance of proper methods of boiler-feeding whether by themselves or firemen.

2. The steam pressure should be kept approximately within the limit of ten pounds.

3. Opportunities for storing hot water in the boiler should be improved when this can easily be done, to help the engine when the work is heavy, and to save coal.

4. Surplus steam should not be permitted to blow off. When the water in the boiler is up to the working limit, the surplus steam should be used for heating the water in the tank.

Saving coal is important; but *safety of trains,* and their *prompt movement,* are still more important, and no risks of damage or delay should be incurred in order to save fuel.

RULES FOR USE OF STEAM.

1. In starting, steam should be used so as to avoid jerking trains or slipping driving-wheels. Slipping should be prevented by throttling steam or using sand.

2. In hauling trains, steam should be used with as short cut-offs as possible consistent with the work required; and with the throttle wide open when necessary to make the engine work properly at the shortest cut-off.

3. When the shortest possible cut-off is being used, speed must be controlled by throttling the steam.

4. Unless there is a train to meet or work to do, the full running time should be used between stations, to enable the engine to haul the train most economically.

TEMPERATURE OF STEAM AT DIFFERENT PRESSURES.

Showing the temperature of steam, at different pressures, from 1 lb. per square inch, to 200 lbs.; and the quantity of steam produced from a cubic inch of water, according to pressure:

Pressure in lbs. per square inch.	Corresponding temperature, by Fahrenheit thermometer.	Cubic inches of steam from a cubic inch of water, according to pressure.	Pressure in lbs. per square inch.	Corresponding temperature, by Fahrenheit thermometer.	Cubic inches of steam from a cubic inch of water, according to pressure.
1	102.9	20954	28	247.2	939
2	126.1	10907	29	249.2	909
3	141.0	7455	30	251.2	882
4	152.3	5695	31	253.1	855
5	161.4	4624	32	255.0	831
6	169.2	3901	33	256.8	808
7	176.0	3380	34	258.6	786
8	182.0	2985	35	260.3	765
9	187.4	2676	36	262.0	746
10	192.4	2427	37	263.7	727
11	197.0	2222	38	265.3	710
12	201.3	2050	39	266.9	693
13	205.3	1903	40	268.4	677
14	209.0	1777	41	269.9	662
15	213.0	1669	42	271.4	647
16	216.4	1572	43	272.9	634
17	219.6	1487	44	274.3	620
18	222.6	1410	45	275.7	608
19	225.6	1342	46	277.1	506
20	228.3	1280	47	278.4	584
21	231.0	1224	48	279.7	573
22	233.6	1172	49	281.0	562
23	236.1	1125	50	282.3	552
24	238.4	1082	51	283.6	542
25	240.7	1042	52	284.8	532
26	243.0	1005	53	286.0	523
27	245.1	971	54	287.2	514

Pressure in lbs., per square inch.	Corresponding temperature, by Fahrenheit thermometer.	Cubic inches of steam from a cubic inch of water, according to pressure.	Pressure in lbs., per square inch.	Corresponding temperature, by Fahrenheit thermometer.	Cubic inches of steam from a cubic inch of water, according to pressure.
55	288.4	506	83	316.1	348
56	289.6	498	84	316.9	344
57	290.7	490	85	317.8	340
58	291.9	482	86	318.6	337
59	293.0	474	87	319.4	333
60	294.1	467	88	320.3	330
61	294.9	460	89	321.1	326
62	295.9	453	90	321.9	323
63	297.0	447	91	322.7	320
64	298.1	440	92	323.5	317
65	299.1	434	93	324.3	313
66	300.1	428	94	325.0	310
67	301.2	422	95	325.8	307
68	302.2	417	96	326.6	305
69	303.2	411	97	327.3	302
70	304.2	406	98	328.1	299
71	305.1	401	99	328.8	296
72	306.1	396	100	329.6	293
73	307.1	391	110	339.2	271
74	308.0	386	120	345.8	251
75	308.9	381	130	352.1	233
76	309.9	377	140	357.9	218
77	310.8	372	150	363.4	205
78	311.7	368	160	368.7	193
79	312.6	364	170	373.6	183
80	313.5	359	180	378.4	174
81	314.3	355	190	382.9	166
82	315.2	351	200	387.3	158

*WHY ENGINES DO NOT STEAM.

"Nothing is more unpleasant to an engine crew or train dispatcher, and in fact every one who is in any way responsible for the condition, than for the report to be sent over the wire, 'Engine not steaming.'

"The next thing is to ascertain the cause, if the failure to steam is something new to the engine; if it is a chronic condition the cause will no doubt be known, for even with pooled engines they have reputations the same as people. It may be on account of leaky flues or firebox sheets, improper firing by reason of a new or incompetent fireman, improper handling of the engine by engineer, overpumping, poor coal, flues or grate openings stopped up, leaky steam or standpipe, or some disarrangement of the front end draft appliances.

"If the engine is overloaded, then the fault is with the dispatcher or those in authority over him. If it is a chronic case of not steaming, the engine having been frequently reported as in that condition and the fault not remedied, then the fault lies on the roundhouse force for not doing the work. Quite often half done work or work that should have been done being utterly neglected, is the cause of engines failing to steam. When first leaving the division terminal the engine will do fairly well with a clean fire, but gradually she gets worse and worse as the fire becomes bad, and finally an engine failure is recorded. False economy may be responsible for a small

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part of it, but neglect is responsible for the greater part of such troubles and failures. Too little attention is paid in many roundhouses to the report on the work book, 'Engine not steaming.'

"The roundhouse foreman charges it to the crew or the coal, and thinks if she gets over the road once that way she will again, and lets the engine go until her record is so bad that something has to be done.

"So long as the front-end draft appliances and the flues in the firebox *look* all right the engine ought to steam, and so she is sent out for the engine crew to fight the same old fight over or make another failure.

"Too much is trusted to appearances, and nothing is more deceptive as to true conditions than the outward appearance of tubes after their firebox end has been interviewed by a man with a short auger. Keeping the tubes open is a thing that should be closely looked after, yet it is one that is too generally neglected. Boring out flues is work that is too often done with a lead pencil on the work book or a short auger in the firebox end of the flues, either method leaving the tubes in the same condition, namely, that of being stopped up solidly. The best place for short flue augers is the scrap pile. The man who has charge of boring out flues should be a reliable man, if one can be obtained. Quite often two men will spend hours in a firebox under pretense of opening up the flues thoroughly of some engine, when in reality they are doing nothing but killing time, and the engine goes out and makes the same old record of not steaming. Of course, it can not be the flues now, for they were all opened up before the engine went out, so the nozzles are bushed or bridged, the draft is forced harder through the good tubes, and more coal is burned. The true con-

dition of the tubes could only be learned by examination, as the men who failed to do their work will not speak of their own neglect.

"It would be a matter of economy, where many engines are handled at a roundhouse each day, to pay the man in charge of this work more money per day than the ordinary roundhouse worker and then hold him responsible for results. The extra cost would be saved in fewer engine failures and overconsumption of coal.

"If flues were bored out regularly and thoroughly they could be kept open easily. Compressed air could be used if they were blown out each trip. Another cause of neglect to bore out flues and keep the flue sheet clean is the brick arch, just as it causes neglect of leaky flues when the work needs to be done while the arch is still hot.

"An engine comes in and is to go out as soon as it can be made ready. The fireup man knocks off what honeycomb he can get at easily above the arch, pokes the ash out of the end of the flues that can be seen from the firebox door; perhaps he cleans out the openings in the grates and perhaps he does not; lights a fire on the grates and announces the engine ready as soon as she makes steam.

"On the surface everything looks all right, but it is not all right. Back of the arch is a solid sheet of honeycomb over the flue sheet, and many flues are stopped up solid and the engine goes out and makes a failure, or the crew worries along over the road without steam, are on duty excessive hours and burn more coal by far than should have been necessary before the terminal is reached.

"Where a brick arch is employed the top tubes receive more of the draft than the lower ones, and consequently the bottom rows of tubes stop up more easily.

"Compressed air for blowing out tubes behind the arch would be an excellent way, as a device could be made to use behind the arch. Where engines can not lay at the terminals long enough for the arch to cool and the work to be properly done on the engine, the brick arch should not be used, as it is more of a detriment than a benefit.

"Another thing that is often neglected is keeping the opening clear between the arch and the flue sheet, and the top of the arch free from the refuse that accumulates on it.

"These are things that should be attended to after each trip and only in case of great need should an engine be turned out of a terminal with only the fire cleaned and other firebox work let go, because the engine is in good shape. If this policy is continued for a while it is safe to assert that that particular engine will not be in good condition very long.

"The demand for power has been in excess of the supply, and this, added to the present tendency to keep engines moving all the time, has been injurious to the engines and expensive for the companies. As the revenue earners of the railroads, the engines should receive the best of care. What would the general manager of a railroad think of a farmer who, with a big crop to put in, starved and neglected the care of his horses? But that is what the average general manager of a railroad is doing for his engines these days.

"Grates should be designed to suit the coal used, a hard or slaty coal requiring more grate opening than a soft, clean coal. An engine that is poorly arranged for draft will consume much more fuel than one properly drafted, because gases can escape unburned and half-burned coal is shaken into the ashpan in an effort to

increase the draft, and when steam is shut off the dismal song of the blower commences in an effort to get steam enough to make the next town.

"Allowing the ashpan to fill up so as to shut off or even hinder the draft will spoil an engine's steaming. Many firemen assume that the ashpan on large engines are designed to hold all the ash of a trip, regardless of how long the trip may be or what its conditions. Cleaning an ashpan when it needs it will often save the fireman far more work in other directions than that employed in cleaning the pan, in addition to the satisfaction of having steam. Air must enter the ashpan and pass up through the grates and fire for an engine to steam, no matter how admirable the front end arrangement may be.

"The diaphragm plate should be far enough away from the front flue sheet to give a free opening for the passage of the smoke and gases, and slope away from the sheet toward the bottom.

"The nozzles should not be compelled to force the draft through the flues. The opening should be large enough to care for the steam from the cylinders without back pressure.

"If the movable part of the diaphragm plate comes down on the road, the front end can be opened and a rod run in one of the flues to hold it up to its own proper level.

"Netting in the front end should be put in sloping, as it will clear of cinders better, and it should be small enough so that the exhaust will clean it thoroughly.

"If the petticoat pipe comes down on the road the exhaust will be deflected from the stack or to one side of it and the engine will not steam, as the vacuum in the

front end will be destroyed. This can only be fixed on the road by allowing fire to cool down until the front end can be entered. As this means quite a delay it is better to go on and get in with the engine if possible and have the work done at the terminal.

"If cylinders work on the saddles it will cause leaky steam pipes and a non-steaming engine. A blow in the front end that can be plainly heard in the cab when the firedoor is open is a warning of a leaky steam pipe or stand pipe joint. If the leak was only a minor one, it might not blow hard enough to be heard in the cab. Cinders blown away from around the bottom of the stand pipe or lower steam pipe joints is another indication of their leaking. Opening the front end while there is steam in the boiler and opening the throttle will show the location of a leak of this kind.

"The top joints of the steam pipes are sometimes neglected because they are more difficult to get at on account of a man having to pass through the trap door in the netting to examine them. A blow from the top steam pipe joints will injure the steaming of an engine more than one from the bottom joints, as it blows in a line to do more injury to the exhaust from the nozzles.

"An engine with a leaky steam pipe or stand pipe joint will steam harder on a hill than on a level, as the blow will be greater in the front end and the draft more injured in consequence.

"Improper handling of an engine so that she will not steam is not excusable. Beating an engine out of steam and water except in some extreme case is far from evidence of a good engineer. Anybody can beat them.

"Overpumping an engine is plain evidence of carelessness or neglect, which is much the same.

"An injector should not be started when pulling a train out of town until the train has gained way, the lever has been hooked back and the maximum steam pressure has been obtained, as it is possible to avoid doing so. After the lever has been hooked back the steam drain by the throttle is not so great, the fire is burning at its best and the water thrown by the injector will affect the steaming of the engine scarcely at all, if any, when injector is started. Where water is low in the boiler this course can not always be followed, but it should be when possible.

"The supply of water furnished a boiler should not exceed the amount being converted into steam when the engine is working, and on local freight runs it can be something less, as the amount lost can be regained at the next stopping place with economy in coal, as the steam can be kept down and not blown away through the pops.

"With a new fireman on an engine one expects steam troubles, as the business is not learned in a mile or a day, but if the fireman is an experienced man it is only neglect or carelessness on his part when he fails to do his work. Neglect to handle the grates so as to keep the fire light, to keep the ashpan clean enough so the grates can be moved when necessary and the fire receive proper draft, and to put coal in the firebox when and where needed is no more excusable than overworking or over-pumping an engine."

*CATECHISM ON THE CARE OF BOILERS.

Question 1. What part of a locomotive is it the most important to have at all times in a first-class condition in order to incur the least possible danger of an engine failure when the locomotive is on the road in service?

Answer. The boiler.

Q. 2. Why is it so important a factor in locomotive operating?

A. On account of it making and containing the steam which performs the work of hauling the train. With a good boiler free from leaks under any ordinary condition, plenty of power to do the work will be assured; even where the machinery is much worn the engine will still be capable of doing good work. All parts of a locomotive should be kept in good condition, but the boiler should be given the greatest care, and in speaking of the boiler, the firebox in these remarks is considered to be a part of the same.

Q. 3. Should a boiler be given good care from the time that it is first put in service, or should the care commence when the boiler from usage begins to show the need of it?

A. Good care should be given a boiler from the day it is put in service to get the greatest possible wear out of it and the best results at all times. Because a boiler is new and clean, neglect to wash it out thoroughly is only laying up future trouble for all concerned, for such

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neglect means scales and mud in the boiler and that means leaks. For the fireman to allow the steam to go down and the fire to grow low, because he knows he can "pick her up" whenever he wants to, is breeding more of the same sort of trouble. Proper firing up and avoiding the use of the blower with a low fire most of all, and careful inspection with the repairing of any minor defect that is found, will do much to keep a boiler in good condition.

Q. 4. What is one of the prime causes of leaky boilers?

A. Scales and mud banking about the tubes and against the sheets.

Q. 5. What is the principal cause of their formation?

A. Impure water.

Q. 6. How are they formed?

A. As evaporation of the water takes place the carbonate of lime is precipitated, forming scale. This process continues, and as time goes on the scale becomes thicker and thicker and the water is thereby removed farther and farther from the sheets, staybolts and flues, with a consequent injury to them. One sign of scale or mud in a boiler is the flue sheet "honey combing," or coating over when on the road; another is small pieces of unburned coal clinging to the sheets.

Q. 7. What effect will this scale formation have on the sheets and tubes?

A. It will cause them to overheat.

Q. 8. What does this result in?

A. Bulged sheets and collapsed tubes. The sheet becoming too hot grows soft and yields to the pressure from within. It may move slightly away from the scale and allow water to pass in between and cool the sheet, but eventually the scale will reform, the old process will

take place, and as the sheet has lost its elasticity it will remain badly bulged, and unless the scale is removed and it is hammered back into shape it most likely will give away entirely. Under such condition the sheet is said to be mud burned.

Q. 9. What effect has scale on stay bolts?

A. At first it causes only a slight leak. As the scale thickens the leakage grows worse, and as the sheet distends the heads of the bolts as a rule are torn away. The same is true of crown bolts. When sheets become badly cracked they must be replaced or patched, as new staybolts would not hold in the defective sheets. One broken staybolt adds very materially to the strain on those in its immediate neighborhood and a broken staybolt should be replaced at the earliest possible moment.

Q. 10. How can the formation of scale and mud in a boiler be avoided to a large extent?

A. By purifying the water, and by careful, thorough washing.

Q. 11. How is the water purified or softened for engine use?

A. By the use of a chemical in the water in the locomotive tanks; commonly soda ash is used. By the treating of the water at softening plants erected at various stations for that purpose. The use of the automatic blow-off cock is necessary in either case, and to bring about the best results it should be used freely to carry off all the scale kept in a free state by the chemicals in the water.

Q. 12. When is the best time to use the blow-off cock for the removal of sediment?

A. When the engine is not working steam, as the sediment then settles toward the bottom of the boiler and is

drawn off with the out-rush of the steam and water through the blow-off pipe.

Q. 13. Should an engineer feel it his duty to blow out the boiler frequently?

A.. Yes. As often as he can. It will keep the boiler in better condition and it is for his own interest to do this.

Q. 14. What effect has frequent caulking on staybolt heads, tubes and sheet seams?

A. It wears them out rapidly. The head on the flues wears off, as do the heads of stay and crown bolts, seams of sheets and edges of cracks. Often one will hear a boilermaker say, "There is nothing left to caulk." It is better if possible to avoid the cause of leaking than to apply the remedy.

Q. 15. What other causes beside scale or rapid change in temperature or pressure will cause boilers to leak?

A. Vibration, which occurs most in large engines with long heavy flues. Poor material or poor workmanship or both often has much to do with leaky boilers.

Q. 16. Will the removal of the scale or mud and the straightening of a bulged sheet usually give good results?

A. It depends on the condition of the iron. If the "life" or elasticity has not gone out of it good will be accomplished, but if it has there will be no good resulting. After a mud bank forms it will not take long for the tensile strength of the iron to be destroyed.

Q. 17. How are staybolt tests made?

A. By tapping them with a hammer in the hands of an experienced boilermaker. Staybolts break next to the sheet, and many railroads have small holes drilled lengthwise in the ends of the bolts, far enough to pass inside the sheets, so that when a bolt breaks steam and water escaping through the hole will be a warning of the break-

age. It is not safe to run a boiler with broken bolts, as the load that a bolt carries is immediately shifted to its neighbors when it breaks.

Q. 18. Is the same care shown to crown-bar braces and bolts that is shown to staybolts?

A. No. They are more difficult of access and are less looked at for that reason, but they are not so liable to breakage as staybolts are, although some are nearly always found to be defective when a boiler is overhauled. Scales are often so thick on crownbar braces that they sound solid when struck with a hammer, when they are in reality broken, and so they are not detected and a cracked brace pin may be overlooked in the hurry to get an engine repaired and back into service at the earliest possible moment.

Q. 19. If a boiler is liable to leak easily, when on the road, what can be done to avoid it?

A. Keep a light, hot fire at all times, thus keeping the sheets from cooling and contracting. Use soda ash freely in the tank and blow the boiler out often.

Q. 20. Will this not cause a fuel waste?

A. No. While it is a waste, yet it will be a saving in the end. To allow the boiler to leak would involve a greater expense than the cost of the extra coal thus used; in addition there would be the chance of an engine failure, which is to be always avoided if possible.

Q. 21. What part of the boiler is the most liable to give out and cause an engine failure?

A. The flues, by one bursting.

Q. 22. What is to be done when a tube bursts on the road?

A. Plug it with an iron plug furnished for that purpose. The best way is to fashion a wooden plug that will

fit tightly in the flue; this plug should be from 12 to 18 inches long and, as tubes often collapse just inside the sheet, it may save a job of plugging the flue in the front end. Drive this plug in the flue and follow it up with an iron one, and there will be no occasion for the roundhouse man to go over that part of the work when you get in, as the wooden plug will swell and make a safe job of it. Plug the smokebox end. This is often a difficult job under favorable conditions, on account of the location of the burst flue, and one that is well nigh impossible on the road. As a rule, with a burst flue where the engine dies, the best plan is to let her be towed into the terminal and repaired there, as clearing the main line is the vital question now days and it takes too long to do this, even if the means are at hand to fill the boiler after the work has been done.

Q. 23. How much water should be carried in boiler?

A. That depends somewhat on the style of boiler and the kind of water used. A half glass or better if it can be carried without working water in the cylinder. In some localities where the water is bad, water will be carried into the cylinders when it barely shows in the bottom of the water glass. A good level of water helps in getting the train under way and over hard pulls, and the larger the body of hot water in the boiler the better the engine will make steam, for the water delivered by the injector has less effect on it.

Q. 24. Is the water glass always a sure indication of the true water level?

A. No. The top water glass opening to the boiler may become stopped up, thus raising the water in the glass above the true level in the boiler. As long as the water is in sight in the glass and works up and down freely in unison with the main body of water in the boiler

it can be relied on, but if it remains stationary for any length of time grow suspicious. Water glasses should be blown out frequently. Gauge cocks should be tried often to insure their being in good working order in case a water glass breaks on the road where you may not be able to put one in at once without a delay. Besides one will always get a sure indication of the water level from them.

Q. 25. If the water level should fall below the line of safety, what should be done to avoid damage to the firebox and boiler?

A. Bank the fire with fine coal. If it is a bad case, douse water on the fire or shake it out altogether. Don't take chances. If one knows that he is running low on water there is little danger to be apprehended. It is when one thinks there is plenty of water and there is but little that damage is done. Water can not be watched too closely.

Q. 26. Why does variation of temperature cause a boiler to leak?

A. It causes the sheets to shrink away from each other, and the tubes to contract away from the flue sheet. A patch gets hotter than the metal it covers and it is almost impossible to keep one from leaking.

Q. 27. What should a fireman do towards keeping the boiler of the engine he fires at as even a temperature as possible?

A. Keep as bright and thin a fire at all times as possible. At the top of a hill the fire can be allowed to burn down some, but not too low. The injector and blow-off cock can be used to keep down the pressure. There may be places where there is a close run for water and this can not be done but ordinarily it can. Good judgment and careful handling will do much to overcome the weakness of a poor boiler.

*CATECHISM ON STEAM.

Question 1. When water is evaporated by the application of heat, what is formed?

Answer. An invisible gas, called steam.

Q. 2. Is there any common experiment that will prove steam to be invisible?

A. Yes. A tea kettle containing water boiling fiercely will show nothing close to the spout's end, but a short distance from it vapor can be seen. The real live steam is that portion of the jet extending from the end of the spout to where the vapor is visible. The same conditions can be sometimes observed in connection with the escape of steam, from cylinder cocks, particularly on a hot day.

Q. 3. What gives steam its power?

A. Heat, and confining it in a given space.

Q. 4. How is this power utilized?

A. By making use of the property of heat and gas to expand when given an opportunity.

Q. 5. Into what classes may steam be divided?

A. Wet, saturated, superheated, and dry steam.

Q. 6. Describe them.

A. Wet steam is steam carrying a considerable number of water atoms entrained with it. Saturated steam is where no moisture of any moment is held in suspension by the steam. Superheated steam is steam heated to a high degree before being transmitted to the cylinder for use. In locomotive practice this is accomplished by running the steam through a coil of pipes located in the

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smokebox, where it absorbs heat that would be otherwise wasted, and is in close connection with the cylinder. To superheat steam it must be removed from contact with the water. Dry steam is steam free from moisture.

Q. 7. At what temperature does the change from water to steam occur?

A. At 212 degrees Fahrenheit. At the sea level, atmospheric pressure of about 15 pounds per square inch.

Q. 8. How does the temperature vary?

A. With the pressure. In an open vessel water will evaporate at 212 degrees; at higher altitude where the atmospheric pressure is less it will be evaporated at a lower degree of heat, and if one could descend toward the center of the earth a greater pressure would be found and higher temperature must be developed to make steam.

Q. 9. The amount of heat necessary to change water to steam must be greater with a high pressure than a low one?

A. Yes.

Q. 10. Where is the pressure greatest in a locomotive boiler?

A. In the water-legs, where the pressure of the steam and the weight of the water are both present.

Q. 11. What steam pressure indication does the steam gauge of a locomotive give?

A. The steam pressure above the atmospheric pressure.

Q. 12. In what portion of the boiler is steam first generated?

A. At the firebox sheets, where the application of heat is most direct. In fact, the greater part of the steam generation takes place about the firebox, the flues contributing to the result in a minor degree.

Q. 13. How does the steam pass to the surface of the water and escape?

A. On account of its lightness from heat, it rises in the form of bubbles which explode on reaching the surface, releasing the steam. As the water evaporates below and rises as steam, the cooler water from above settles down to replace it. The supply in a boiler would soon be exhausted if it was not replenished.

Q. 14. Will the temperature of steam in an open vessel rise above 212 degrees?

A. No. For it is released as soon as made.

Q. 15. In a confined space, as in a boiler, how does the temperature vary?

A. With the pressure.

Q. 16. What property has steam along with other gases?

A. That of expanding and filling space.

Q. 17. How is this property utilized in using the power of steam?

A. By confining it until a desired pressure is obtained, and then allowing it to escape only in such a manner as will compel it to do certain work before it is free.

Q. 18. What is the pressure dependent upon?

A. The strength of the boiler containing the steam. The pressure is always placed far below what is considered to be the point of safety from explosion of a boiler, as explosions are very costly and undesirable affairs.

Q. 19. How does steam do its work?

A. By being admitted to the cylinders against the end of the pistons, which act on the drive wheels by means of main rods. The steam admitted to the front end of the piston forces it back until a port, called the exhaust port, is placed in connection with the front end of the cylinder

when the steam escapes, the supply of steam to the front of the cylinder being cut off by the advance of the valve and the supply transferred to the rear of the piston.

Q. 20. How does the pressure against the piston decrease with its travel?

A. Inversely with the space or volume it expands to fill.

Q. 21. Explain this.

A. If a cylinder was 26 inches long and steam was admitted for one-half the stroke at a pressure of 100 pounds per square inch and the supply is then cut off, when the piston has reached the end of its stroke the space occupied by the steam would be twice as great and the pressure would be diminished one-half, that is, it would be 50 pounds per square inch at the completion of the stroke.

Q. 22. How can you determine the absolute pressure at any point in the stroke or at its completion?

A. Multiply the absolute pressure by the length of the cut-off and divide by the length of the stroke, or at any point of the stroke beyond the cut-off that may be desired. Thus, 140 pounds pressure $\times$ 8-inch cut-off $=$ 1,120, which, $\div$ 26, the length of the stroke, gives 43 pounds per square inch as its pressure at completion of the stroke.

Q. 23. How can one find the effective pressure?

A. Deduct the atmospheric pressure from the absolute pressure and it will give the effective pressure.

Q. 24. What does a loss of heat involve?

A. A loss of power, which is a financial loss the same as a loss of heat in combustion is a money loss. In the former case it is active power, in the latter latent.

Q. 25. How may this loss of heat occur?

A. In three ways; by radiation, convection and conduction.

Q. 26. What is radiation of heat?

A. The giving off of heat by rays the same as the sun transmits heat to the earth.

Q. 27. What is conduction?

A. The passing of heat along a metal. Firemen are aware how the handle of a slash bar will heat from the end in the fire by conduction when removing clinkers from the firebox.

Q. 28. What is convection?

A. It can be observed best in the heating of water. The particles of water nearest the fire becoming first heated rise to the surface and the colder water from above replaces it. It is a form of circulation brought about by the action of the heat.

Q. 29. Is the degree of conduction in all substances the same and dependent only on the degree of heat to which they are exposed?

A. No. There is a great variation in the conducting power of different substances.

Q. 30. How is this knowledge utilized?

A. To prevent a loss of heat to boilers by covering the exposed parts with some good nonconducting material. Asbestos, or wood, covered with Russia iron, is the material most used.

Q. 31. In addition to the element of safety introduced into boiler building by allowing a wide margin between the pressure carried and the tensile strength of the iron, what other precaution is adopted?

A. Frequent stay-bolt and boiler tests are made by hammer and water pressure.

Q. 32. What prevents the pressure rising beyond a certain point?

A. Valves, called safety or pop valves, adjusted to a

certain pressure by springs and whose under surfaces are acted upon directly by the steam which lifts them from their seat when the pressure in the boiler exceeds slightly the resistance of the springs. There being two of them, there is practically no danger that both would be out of order at the same time.

Q. 33. What pressure is a boiler supposed to stand without giving away in any portion.

A. One-fifth of the tensile strength of the boiler plate.

Q. 34. If the tensile strength of a square-inch of cross-section of boiler plate is 50,000 pounds, why is it necessary to allow only one-fifth of that, or 10,000 pounds?

A. Because of the weakening effect of seams, stay-bolt holes, hand-hole plates, wash-out plugs, and the like on the boiler sheet. Then there is the pitting of the sheet by the action of the water, and the wear and tear incident to service for which to allow.

Q. 35. What is the usual cause given for boiler explosions?

A. Low water.

Q. 36. What is the true cause?

A. Inability of the metal to withstand the strain put on it from within.

Q. 37. To what other causes are they sometimes attributed?

A. To cold water being pumped on to a hot sheet, thereby generating suddenly a powerful gas which rends the boiler plates. Also to the violent opening of a valve, causing a sudden rush of steam, lifting the water and causing the shell of the boiler to collapse.

Q. 38. Are these theories well supported by facts?

A. No. They are often used to shift the responsibil-

ity from the man to blame for the disaster to the man, who, being killed, is beyond the reach of blame. With low water the sheets may be heated to the melting point, or so that the softened sheet would pull over the bolt heads, but then the chances are for a rupture of the sheet and not a boiler explosion. Cold water admitted might damage a sheet by a too sudden cooling, but that is about the worst that happens, *for the water comes in at the front of the boiler and is warmed to a certain degree before it reaches the firebox sheets.* Heat a piece of boiler iron a foot square red hot, and see how hot it will make just one pail of cold water and how much steam it will generate, and draw your own conclusions as to the rest. Opening a valve wide might cause a sudden change of pressure that would damage a boiler, but not enough to cause an explosion.

Q. 39. What is the difference between a rupture of a boiler and a boiler explosion?

A. A rupture is the gradual giving away of any portion of the boiler. An explosion is a violent rending of the parts when the whole shell is damaged to a greater or less degree.

Q. 40. Is there usually any prior indication of the giving away of some part of the boiler?

A. Yes. Bagging or blistering of the sheets, cracks in their surface, stay-bolts and braces breaking, and frequently leaking of seams from one sheet bulging out from the other.

Q. 41. How can these defects be discovered?

A. By a careful inspection by a competent mechanic.

Q. 42. Is testing a boiler by a very high pressure, one much beyond that which it usually carries, a sure sign that the boiler is perfectly safe?

A. No. Everyone has observed a rope that withstood a great strain one day yield to a lesser one the next. Yet the test is a good one and might save trouble. There may be an inherent weakness in a boiler plate that can not be discovered and that will one day cause disaster. A side rod often shows no defect but suddenly parts.

Q. 43. From what part of the boiler is the steam transmitted to the cylinders?

A. From the steam dome located on top of the boiler.

Q. 44. Why is it taken from the dome?

A. Being the highest point in the boiler containing steam, it holds the least water in suspension, and the drier that steam can be supplied to the cylinders the better, as damp steam requires more valve and cylinder lubrication and is not so efficient for doing work.

Q. 45. Is a high boiler pressure a safe indication of dry steam?

A. No. The pressure may be high or low and the steam dry, or the opposite. More saturated steam is used than perfectly dry steam in locomotive practice.

Q. 46. Does a boiler make steam best with a high or low water level?

A. With a high water level, on account of the latent heat in the larger body of water.

Q. 47. Why not carry a high water level at all times?

A. Because the water passes with the steam into the dry pipe and is injurious to the valves and cylinders.

Q. 48. Is all the power in steam utilized before it is exhausted to the atmosphere?

A. No. The compound locomotive is designed to utilize a part of this waste, but owing to frequent failures in service they have not come into general use.

INJECTORS.

The accompanying three plates shown in colors give a graphic representation of the Nathan type "M" non-lifting injector. As its name implies, the water is not lifted by this type of injector. It forces it into the boiler. Accordingly it has to be placed lower than the lowest water level in the tank, which permits water to flow to it as long as any remains in the tank. The overflow pipe, which is connected with the overflow space in the injector body, has its outlet above the highest water level in the tank, and so prevents waste of water when the injector is not working. It is located in a convenient place for the engineer or fireman, usually inside the cab. It is obvious that by locating the outlet in this position the necessity for closing the overflow valve *20* is done away with, unless it is used as a heater. The operating rods *22* and *23* for the water and steam valves are carried into the cab within convenient reach of the engineer or fireman. Plate No. 1 shows the injector in the closed position.

It will be seen, by referring to Plate No. 1, that the parts are indicated thereon as follows: *1* is the injector body. *2* is the yoke. *3* the gland. *4* the yoke packing nut. *5* the yoke nut lock. *6* the steam valve. *7* the steam nozzle. *8* the priming valve and nozzle. *9* the universal joints. *10* the water valve. *11* the water valve bonnet and nut. *12* the intermediate nozzle. *13* the condensing nozzle. *14* the delivery nozzle. *15* the drain plug. *16* the line check plug. *17* the line check valve cap. *18* the overflow pipe. *19* the overflow nozzle. *20*

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the overflow valve. *21* the overflow valve stem and handle. *22* the steam valve handle. *23* the water valve handle. *24* the steam connection. *25* the water connection. *26* the connection to the boiler.

To the right of the Plate is shown an enlarged view of the priming valve and nozzle *8*, the steam nozzle *7*, the intermediate nozzle *12*, the condensing nozzle *13*, and the delivery nozzle *14*.

The colors used to represent the different pressures or conditions are: Live steam from the boiler, deep blue. Condensed steam or steam and water intermingling, green. Atmospheric pressure, orange. Water before it has been in contact with the steam, yellow.

In Plate I, the steam valve *6* and water valve *10* are shown closed, that is, the valves are seated. Water from the tank is shown to have entered the connection *25*, but is prevented from entering the injector by the water valve 10 being closed. Live steam from the boiler has entered the connection *24* and fills chamber *A* surrounding the priming valve and nozzle *8*, but can go no farther on account of steam valve *6* being closed. When in this condition, atmospheric pressure fills chambers *B*, *C* and *D* and the overflow pipe *18*. In practice, however, water valve *10* is usually left partially open so as to be in readiness for immediate operation, in which case the water from the tank entering the connection *25* would flow up and around water valve *10*, in chamber *B*, thence into and through nozzles *7*, *12*, *13* and *14*, into chamber *C* and, unless stopped by the check valve *16*, past check valve *16* into chamber *D* and the connection *26* to boiler.

To operate this injector it must first be seen that the overflow valve *20* and the tank valve are wide open. Then open the water valve *10* a turn or more by means of the

handle *23*. Open steam valve *6* slightly by means of the handle *22*. As soon as steam valve *6* is raised from its seat in the priming valve and nozzle *8*, steam from chamber *A* enters and passes through priming valve and nozzle *8* and mingles with the water in chamber *B*. The steam when coming in contact with the water condenses, but in doing so it carries with it sufficient velocity to force the water through intermediate nozzle *12* and condensing nozzle *13* into the overflow pipe *18* (the connection to overflow pipe *18* is shown in dotted lines at the lower end of condensing nozzle *13*), up to and around overflow valve *20* and out the overflow nozzle *19*. Upon water issuing from the overflow nozzle *19* the steam valve *6* should be opened wider, unseating the priming valve *8* and permitting a larger volume of steam to pass down and around priming valve *8* and through steam nozzle *7*, giving a much greater velocity to the flow of water and forcing it through the delivery nozzle *14*, through chamber *C*, past check valve *16* into chamber *D* and out the connection *26* to the boiler. The quantity of water supplied to the boiler should be regulated by the water valve *10* by means of handle *23*. When sufficient water has been obtained in the boiler, to shut off the injector it is only necessary to close the steam valve *6* by means of the handle *22*, thereby leaving the injector in condition for immediate use when required. By leaving the water valve open the injector will be kept in a much better condition and scales are not so liable to form in the nozzles and injector body and cause trouble.

In cold weather the injector may be used as a heater. To do so, close overflow valve *20* by means of the handle *21* and slightly open steam valve *6* by means of the handle *22*. If the injector should be in danger of freezing, drain

plug *15* may be substituted by a drain cock, and by keeping the tank valve closed when the injector is not in use and opening the drain cock on injector, the water may be drawn off.

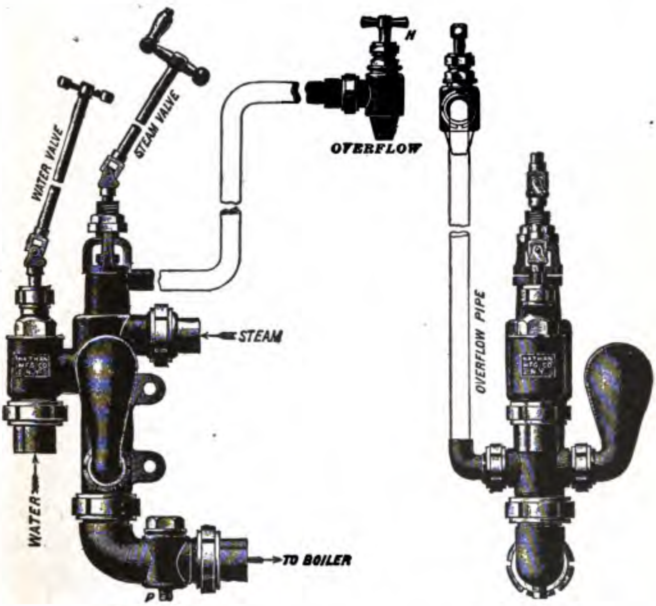

Fig. 63. Fig. 64.

The Nathan Type "M" Non-lifting Injector.

In Figs. 63 and 64 are shown outside views of this injector. Fig. 63 is a front view showing the air chamber opposite the connection to overflow pipe *18*, and Fig. 64 is a side view showing overflow pipe *18*, and the air chamber opposite.

A sectional view of the injector in priming position is shown in Plate II. It will be seen that the overflow valve

20 is wide open. The water valve *10* has been partly opened and water has entered chamber *B*, passed into and around nozzles *7*, *12*, *13* and *14* and into chamber *C*, where its course is interrupted by the check valve *16*. Steam valve *6* has been slightly opened, and steam from chamber *A* is passing through priming valve and nozzle *8* and steam nozzle *7*, and mingling with the water in chamber *B*. This mixture of steam and water in chamber *B* causes the steam to condense, but in doing so it retains sufficient velocity to force the water through the intermediate nozzle *12* and condensing nozzle *13* into the overflow pipe *18* (see connection to overflow pipe *18*, shown in dotted lines at the lower end of condensing nozzle *13*), up to and around overflow valve *20* and out the overflow nozzle *19*, as shown in Plate II. When this condition is reached the injector is ready to operate to force water into the boiler.

A sectional view of the injector in working position is shown in Plate III. When the condition as shown in Plate II has been reached the injector is ready to operate to force the water into the boiler.

By referring to Plate III it will be seen that the steam valve *6* has been opened wide, permitting a larger volume of steam to pass from chamber *A*, through the priming valve and nozzle *8*, downward through steam nozzle *7*, intermediate nozzle *12* and condensing nozzle *13*. The increased velocity given to the flow of water by the larger volume of steam forces the water which has entered chamber *B* past the connection to overflow pipe *18* (at which time overflow check valve *20* seats and the waste of water at overflow *19* ceases), thence into and through the condensing nozzle *14* and into chamber *C*, forcing the line-check valve *16* from its seat, permitting the highly ener-

gized flow of water to enter chamber *D* and pass thence to the boiler.

When the overflow has entirely ceased, the amount of water supplied to the boiler is regulated by the water valve *10*, which is adjusted to suit the circumstances. In Plate III this valve is shown wide open.

It is customary to leave the water valve *10* open, that is, set at its usual working position when not in use. By following this plan there is always a supply of water in the injector body ready for immediate use, and much of the difficulty occasioned by scale forming is thus obviated. To shut off the injector it is merely necessary to close the steam valve *6* by means of the handle *22*.

In cold weather when it is desired to use the injector as a heater, overflow-valve handle *21* should be screwed down, which will hold overflow valve *20* to its seat, and steam valve *6* opened slightly by means of the handle *22*. This will cause a back current of steam to mingle with the water in chamber *B*, and thence pass through the water connection *25* and into the tank, preventing freezing. Sometimes the drain plug *15* is replaced with a cock, so that by closing the tank valve the water may easily be drained off from the injector and overflow pipe by opening the cock.

*CATECHISM ON INJECTORS.

CATECHISM ON BELL RINGERS.

Question 1. What are main working parts of an injector?

Answer. The steam nozzle, combining tube, delivery tube and the overflow nozzle.

Q. 2. What is the use of each of these parts?

A. The steam nozzle directs the steam to the combining tube, where it unites with the water. The combining tube is that which its name implies, the tube where the water and steam combine; the steam is condensed and imparts its velocity to the water, moving into the delivery tube, where the greatest velocity is attained, and passing through the delivery tube and branch pipes, forces the boiler check valve from its seat and enters the boiler.

Q. 3. How are the tubes arranged in regard to each other?

A. They are in exact line with each other.

Q. 4. What is the shape of the tubes?

A. Tapering. The small ends of the steam nozzle and the combining tube all face toward the small end of the delivery tube.

Q. 5. What three kinds of injectors are commonly used on locomotives?

A. The non-lifting, the lifting and the restarting injectors.

Q. 6. Explain the meaning of the different names.

A. The non-lifting injector is one so located on the

*W. L. French.

engine that the supply of water flows to it. A lifting injector is one where a jet of steam discharges, by opening an overflow valve through a waste pipe, thus creating a vacuum. This causes a suction through the overflow pipe and water flows from the pipe. The steam throttle being opened, the water is forced through the delivery tube into the boiler. Closing the overflow valve stops the flow of steam from the waste pipe after the injector has been started to work.

A restarting injector is one that, if the supply of water is stopped temporarily, it will resume work as soon as the supply of water comes back to it, as in the case of an injector breaking from low water in the tank or on account of rough track.

Q. 7. Why will not a lifting injector restart when it breaks?

A. On account of the injector having a closed overflow the steam flows back through the tank hose into the tank when the injector breaks, and the water in the tank is thus kept from reaching the injector so that it could restart.

Q. 8. Why will the restarting injector go to work automatically when it breaks?

A. Passages are provided for the escape of the steam to the atmosphere when the injector breaks, and the water still being furnished to the injector it goes to work automatically.

Q. 9. What tube measures the capacity of the injector?

A. The delivery tube, it being the smallest tube in the injector.

Q. 10. Explain how the water delivered at the boiler check overcomes the boiler pressure at the boiler check and enters the boiler.

A. Because the water moving through the branch pipe has pressure, velocity and weight, while the pressure within the boiler is at rest and is in this manner overbalanced.

Q. 11. About what is the ratio of water and steam combining in the ordinary injector?

A. About fifteen parts of water to one of steam.

Q. 12. Why is the delivery tube made small at the end where it receives the water and then expands?

A. To give the water greater velocity when it escapes from the tube.

Q. 13. What causes the lifting effect in the lifting injector?

A. The vacuum being in front of the water supply from the tank, the air pressure on the water in the tank forces the water up into the injector.

Q. 14. If an injector had been working in a satisfactory manner and suddenly stopped working, where would be the first place to search for trouble?

A. In the water supply. The tank valve might have become disconnected. The strainer might be stopped up or fine coal or cinders might have gathered about the tank valve.

Q. 15. In any of these cases how would you remove the obstruction without stopping engine and taking hose down?

A. Close overflow-valve and blow a heavy jet of steam back through the tank hose from the injector steam throttle; if this does not suffice it will be necessary to take the hose down at the first opportunity. If air sucks into feed pipe at any point injector will break, so look out for this trouble also.

Q. 16. What will cause an injector to fail to prime?

A. Low water in the tank, leaky boiler check valve or other leak of steam to injector that would destroy the vacuum, or an overflow pipe stopped up.

Q. 17. In case an injector was not used for some time what might occur?

A. Boiler check valve might become corroded and stuck fast to seat so that injector would not work, and tubes might also become corroded and partly stopped up.

Q. 18. If a boiler check valve would only partly lift when injector was started to work what would be the result?

A. Water would be thrown out on the ground through the overflow pipe.

Q. 19. Under either of these conditions can anything be done to remedy or help them?

A. Open cock to frost pipe and tap boiler check-valve cage and try to work the injector; this will sometimes loosen the valve from its seat and injector will go to work properly.

Q. 20. What effect has loose tubes on the working of an injector?

A. It will cause the injector to break.

Q. 21. If the steam furnished by the injector steam throttle is not all condensed what is the result?

A. Injector will not work or will only partly take up the water. Either reduce the supply of steam or increase the supply of water.

Q. 22. Will variation of steam pressure on boiler have any effect on the working of an injector?

A. Yes. If the steam pressure falls considerably the supply of water must be decreased or the injector will not take it all up, or the boiler will be oversupplied with water.

Q. 23. What effect has bad water on injectors?

A. It corrodes or limes them up and they soon get in a condition where they will not work, and a bath in muriatic acid will be necessary to restore them to a good working condition.

Q. 24. Which injector will corrode the more quickly, a lifting or a non-lifting injector?

A. The lifting injector, on account of steam being continually in the body of the injector. In some localities where the water is quite bad and injectors corrode quickly, only the non-lifting injectors are used to avoid changing and cleaning injectors so often.

Q. 25. Must air enter tank above water as fast as the water is taken out by the injector?

A. Yes. In all cases.

Q. 26. What depends on the good condition of the injectors?

A. The safety of the boiler and the proper handling of the train.

Q. 27. How should a boiler be pumped on a through train where stops are infrequent?

A. The injector must be worked hard enough to maintain the water level in the boiler.

Q. 28. How should a boiler on a local train be pumped?

A. So that the water level will fall some between stations. The supply can be replenished while doing station work and the pops thereby kept from blowing off steam, and a brighter fire be kept burning on the grates.

Q. 29. Is it desirable or not to have a good supply of water in the boiler when pulling out of town with a train?

A. Yes. The injector need not be put to work where there is plenty of water in the boiler until fire is in good shape and steam pressure at maximum.

Q. 30. What should an engineer know about the injectors on the engine he is taking out before starting on a trip?

A. That both work in a satisfactory manner. If only one injector is used all the time the chances are that the other one will fail when most needed.

Q. 31. Is the water glass indication of the water level always a safe standard by which to gauge the water in the boiler?

A. Yes. If the water level is in sight and moving freely in the glass, otherwise it is open to suspicion. If water is up or down out of sight in glass the gauge cocks should be used frequently to determine true water level. Boilers are more frequently burned with the water supposedly up out of sight, and therefore indicating a plentiful supply of water in the boiler, than when the water is known to be really low, for when one knows that the water is low chances are not taken on a burned boiler. Gauge cocks and water glass cocks should be frequently bored out.

Q. 32. How is a water glass replaced when broken?

A. Close water glass cocks and open blowout cock to water glass. Remove plug in top of top water glass cock, packing nuts and old gaskets. Put water glass down through top gasket and both packing nuts and bottom gasket to bottom of lower water glass cock. Screw packing nuts on lightly with hand and replace plug on top of upper water glass cock. Close blow-out cock and open water glass cocks lightly at first, and then the desired amount. Note if the water works free in the glass to show that the glass is not stopped up.

Q. 33. What device is used to operate the bell without the use of the bell cord?

A. The automatic bell ringer.

Q. 34. What force operates it?

A. Compressed air. Steam bell ringers were formerly used, but compressed air has taken the place of steam for bell ringers.

Q. 35. Describe the air bell ringer.

A. It consists of a crank attached to the bell yoke; from this crank a small rod passes down inside of a pipe or hollow shaft which is connected with the piston rod. The air cylinder is attached to the bottom of the bell stand and contains the valve that controls the admission, cut-off and exhaust of the air, and the piston and piston rod.

Q. 36. How is the exhaust of the air from the cylinder provided for?

A. An exhaust port is drilled through the head to the atmosphere.

Q. 37. Where is the compressed air taken from that operates the bell ringer?

A. From the main reservoir.

Q. 38. How is the air admitted to the bell ringer?

A. By a globe valve located in the cab, and is conveyed to air cylinder by a small pipe connected to main reservoir pipe below engineer's brake valve.

Q. 39. How does valve in air cylinder work?

A. It works over air inlet port and exhaust port. The admitted air strikes the valve in the cylinder and forces the piston up until the exhaust port is opened and the admission is closed by the movement of the valve, when the air escapes and the weight of the bell pushes the piston down and the valve to its former position, when, the admission port being opened, the piston is again forced up by the action of the compressed air.

Q. 40. How is the travel of the crank rod adjusted to regulate the motion of the bell?

A. By an adjusting screw.

Q. 41. What causes a bell to turn over and over instead of moving back and forth as intended?

A. Too much crank rod travel or too much air admission. Sometimes more air must be admitted to start a bell than is necessary to move it properly after it is once started, and if the supply is cut down the bell will work properly.

Q. 42. What kind of oil should be used in the air cylinder of a bell ringer.

A. Valve oil, used sparingly. The yoke bearings on the bell stand should be kept well oiled to reduce the friction and wear.

LUBRICATORS.

The eight Plates in colors show sectional views of a bull's-eye pattern Detroit No. 21 Lubricator.

The increased boiler pressure used in modern locomotives created conditions which practically unfitted the old style of lubricator for the service intended, among which may be mentioned broken glasses, often resulting in serious injury to the enginemen, cut valves, leaky joints, schedules demoralized and a rapidly increased cost of maintenance. The efforts of the manufacturer to safeguard the employe and the property of the railroad company caused the device to become so complicated that it was looked upon with suspicion and disfavor by those having to do with it. This situation became a matter of serious thought on the part of the manufacturers, the result being the production of the present type of lubricator, which embodies safety, simplicity and economy. One of the most important features of the Detroit No. 21 lubricator and its class is the adoption of a sight-feed glass that will not break under any condition of service, thereby removing all danger of injury to enginemen and delays incident to such breakage. It is claimed for this lubricator that it occupies less space in the cab, has fewer parts, a less variety of parts and less metal joints, there being no arms to shake loose, causing leakage, and no valves on the inside or outside not necessary in the operation of a perfect lubricator.

The sight-feed glass and its packing are so designed and located as to prevent sudden and extreme changes

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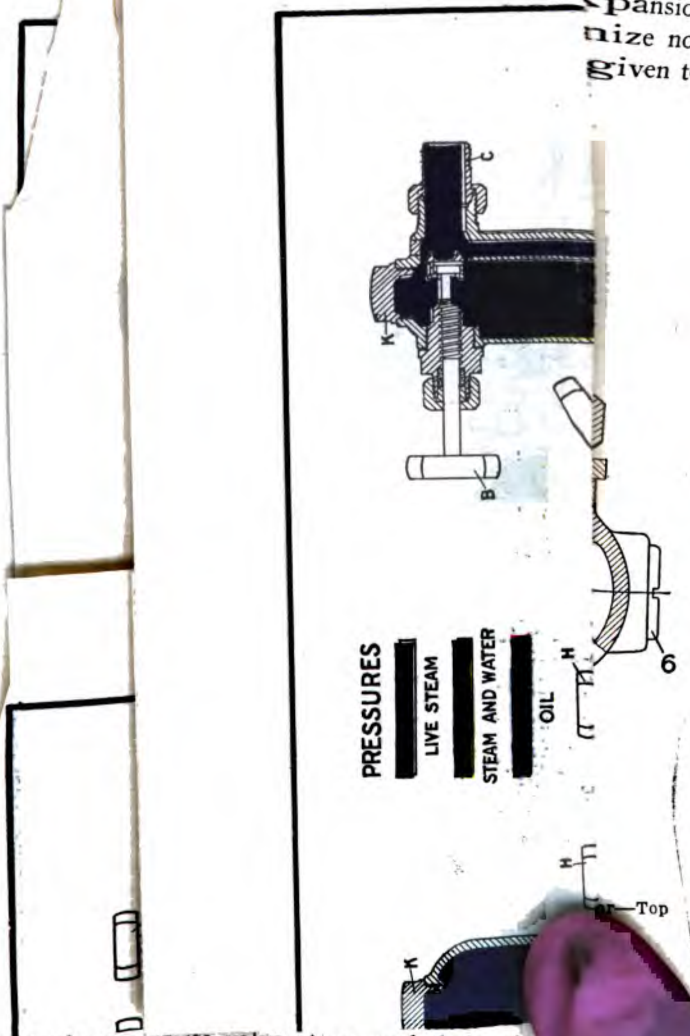

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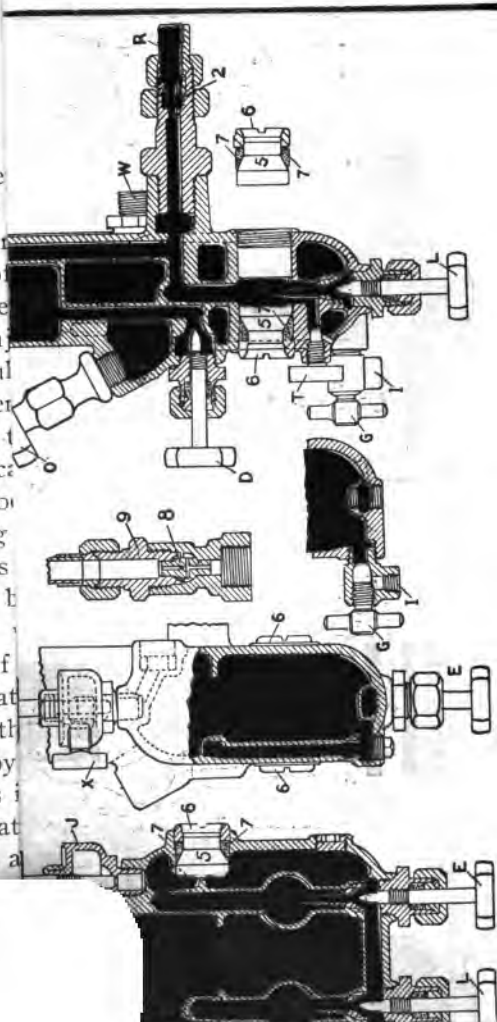

in temperature, allowing perfect freedom for expansion or contraction. The packing will neither vulcanize nor blow out. Additional strength and durability is given to

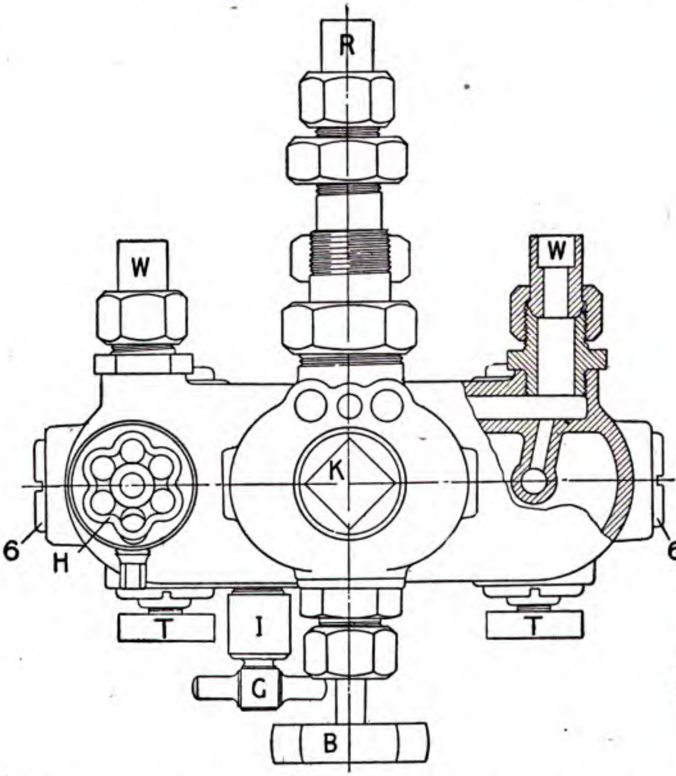

Figure 65. Detroit No. 21 Triple Feed Locomotive Lubricator—Top View.

this lubricator by a better disposition of the metal formerly used in arms, by-pass valves, etc., as may be seen by a glance at its valve stems and their stuffing boxes.

Other claims made in its favor are: Simplicity in construction and operation; uniform temperature at which the oil is maintained; absolute regularity of the feed; visibility of all feeds from two sides, and saving in oil. An additional valve has been placed at the top of the lubricator to control the supply of steam from the boiler, making the device self contained.

Plate IV shows the lubricator in operation, the oil having been more than half fed out. *A* is the oil reservoir, *B* the steam valve, *C* the steam connection, *D* the water valve, *EE* the feed regulating valves to right and left-hand cylinders, *F* the condenser, *G* the drain valve, *H* the hand oiler stem, *I* the drain valve body, *JJ* the auxiliary oilers; *K* the condenser plug, *L* the feed regulating valve to air pump, *O* the filler plug, *R* the coupling to air pump, *TTT* the sight-feed drain stems, *WW* the couplings to right and left-hand cylinders, and *X* the hand oiler filler plug. *1* is the feed nozzles, *2* the air brake check, *3* the oil tube, *4* the gauge glass reflector, *5* the sight-feed glass, *6* the feed glass packing ring, *7* the rubber packing, *8* the steam chest valve check, and *9* the steam chest valve cap.

The following hints and directions for operating this lubricator are given by the manufacturers:

Steam for lubricator should be taken from turret if large enough, or from dome through an independent dry pipe of one-inch iron pipe size or its equivalent. When the lubricator is first applied, blow out thoroughly, then close all the valves.

To Fill.—Remove filler plug *O* and fill the reservoir with clean, strained oil.

Note.—If there is not sufficient oil to do so, always use water to make up the required quantity. This will enable the feeds to start promptly.

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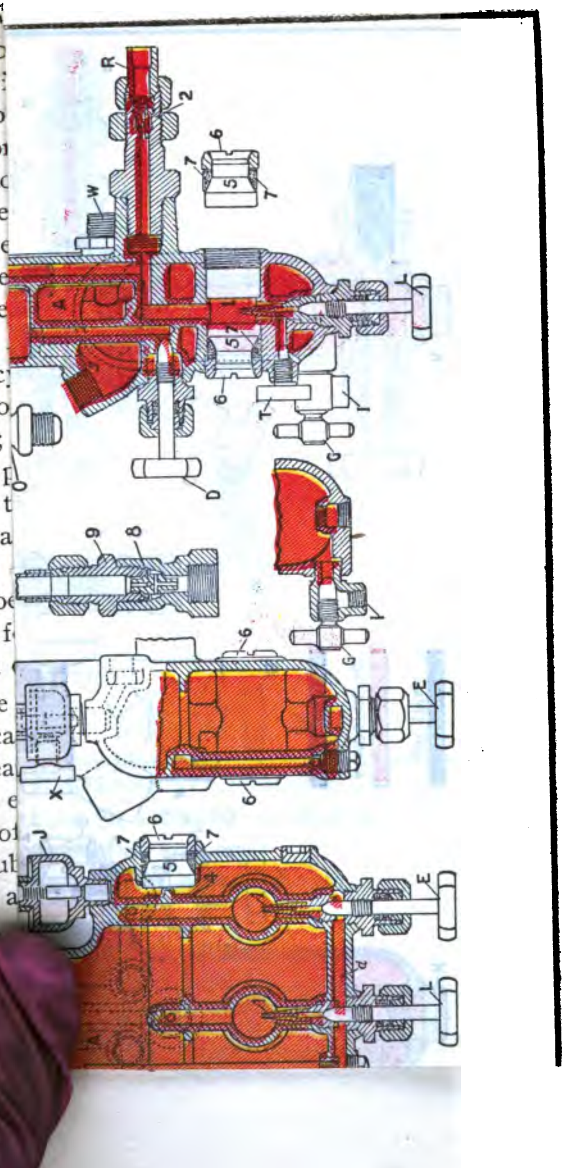


Steam Valve.—The regular boiler valve should be left wide open, and the steam valve *B* at top of condenser must also be kept wide open while the locomotive is in service.

To Start Lubricator.—1st. Be sure that the regular boiler valve is open. Then open steam valve *B* at top of condenser wide open and keep wide open while lubricator is in operation. Allow sufficient time for condenser and sight-feed glasses to fill with water. 2nd. Open water valve *D*. 3rd. Regulate flow of oil to right and left cylinders by valves *EE* and to air pump by valve *L*.

To Operate Auxiliary Oilers.—See that valve *H* is closed. Then open valve *X* and fill body of oiler. Close *X* after filling and open valve *H*.

To Re-Fill.—Always close valves *EE* and *L* in advance of valve *D*. Open drain plug *G*, then filler plug *O*. Refill and proceed as before.

If at any time it becomes necessary to fill the lubricator with cold oil and the engine will remain out of service for some hours, do not fail to turn on slight steam pressure from the boiler and open valve D in order to prevent excessive pressure from expansion of the oil.

Blowing Out.—Blow out lubricator once a week or oftener if necessary.

Getting New or Re-Built Locomotive Ready for Service.—In getting a new or re-built locomotive ready for service, disconnect oil pipes at steam chest, and blow out thoroughly both oil pipes and automatic steam chest valves; also disconnect coupling to air pump and see that choke is free. Do this several times while getting the engine ready for service.

Do not screw up too tightly the feeding-glass follower, as this will only serve to injure the packing. There is no

danger of leakage at this point, as the glass and packing are so designed that the greater the pressure from the inside the better the joint.

Automatic Steam Chest Plugs and Valves.—The function of these automatic steam chest plugs and valves is two-fold: First, that by their use and location the lubricators feed against a constant boiler pressure and not against a fluctuating pressure, as was the practice in the earlier type of lubricators. Second, the valves or chokes restrict the flow of steam to the steam chest to that volume that will balance the feeds to a uniform rate, regardless of the position of throttle or lever.

These valves are so designed and constructed that they are reversible and have about 3-16-inch lift, this movement between the two seats enabling the valve to be self-draining, a very important feature, as it prevents scale or any foreign substance from accumulating or restricting the flow of oil and steam to the steam chest or cylinders. The openings in these valves are 5-64-inch.

The constant flow of steam through the lower openings in these valves will enlarge these openings in time to such an extent that the lubricator will feed faster while the locomotive is drifting or at rest; in fact, that condition is the exact cause for the engineer to complain that the locomotive feeds race. All that is necessary to rectify this condition is to reverse ends of valves. When both ends have become worn out, the valves must be replaced by standard ones of the proper opening.

A reasonable degree of attention regarding these valves in the automatic steam chest plugs will result in a very satisfactory working lubricator and a decided increase in valve oil mileage, two factors that are highly desirable.

The manufacturers give some good advice under the head:

DON'T FORGET.

That a lubricator will give better results if it is cared for intelligently.

That the water passage will close up with sediment and cut off the water between condenser and oil reservoir as completely as if the water valves be closed.

That a lubricator should be blown out at least once a week and in bad water districts oftener.

That a piece of soap put in the reservoir about once a week will keep it clean, also the glasses.

That valve oil and engine oil should never be mixed and put in a lubricator. The temperature of the lubricator is too great for engine oil; besides, the engine oil will carbonize. As soon as it passes up and out of sight-feed chamber it comes in contact with the high steam temperature and all lubricating properties have been destroyed.

That particles of carbonized engine oil have no more lubricating properties than powdered charcoal would have.

That if your valve oil supply is not sufficient to reach a terminal point at the regular rate of feed, feed the lubricator slower, carry less water. Don't wet the valves; run with a lighter throttle, a longer cut-off, and do not allow your engine to drift into town or down hill, but work a very light throttle.

That the chokes at the steam chest are constantly cutting away by the action of the steam.

That the chokes balance a lubricator.

That the steam valves on a boiler and on the one on top of the condenser must be opened wide in order to counteract the two steam chest pressures.

That there are a limited number of drops of valve oil in one ounce, one pound, one pint and a lubricator.

That the quantity of oil per mile increases as the speed of a train decreases and it correspondingly decreases as the speed of the train increases.

That as the engine is running very slowly on the hill the lubricator is increasing the quantity of oil per mile in proportion to the speed.

That salt water is more buoyant than fresh water, and for that reason it will force the drop of oil off the feed cone sooner. There would be more drops of oil in a minute than when the water in the sight-feed chamber was fresh, but the quantity of oil would not be any less.

That the water in the sight-feed chamber becomes salty and it is carried over from the boiler by the mechanical action of the stream.

That there is a constant evaporation taking place in the condenser of any kind of locomotive lubricator. The same is true in the outlet of the sight-feed chamber.

That there are two principles involved in a locomotive lubricator. First: Hydrostatic. The hydrostatic pressure ends on the point of the feed cone. From that point to the surface of the water in the sight-feed chamber the oil travels at the rate of thirty feet per minute. Second: The oil coming in contact with the steam is carried to the steam chest by the laws of gravity, heat and motion.

That the chokes of the steam chest give better results. That the boiler pressure reaches down to the steam chest, chokes and prevents back pressure from backing up into the oil pipe, also the lubricator is feeding against a constant boiler pressure and not against a fluctuating oil pipe pressure as when the chokes were located at the lubricator.

That the oil should be strained. We do not guarantee our lubricators to feed sawdust, coal, waste or any such substances.

Plate IV shows the lubricator in operation, that is, the feed regulating valves are open and the lubricator feeding drops of oil. We will now assume that the oil in the lubricator has all fed out. By referring to Plate V it will be seen that water now occupies all parts and passages of the lubricator body and condenser, formerly occupied by oil, to the height of the steam inlet. At this stage we desire to particularly call the reader's attention to this important fact—that both the oil tube *3* and oil feed chamber *d* now contain water.

We will assume that the engine crew wishes to give the lubricator a thorough blowing out, not only the condenser *F* and the water passages, but the oil tube *3*, oil feed chamber *d* and sight-feed chambers as well. It is of the greatest importance that we should do things in a methodical way, keeping in mind that there is a right and a wrong way to do these things. For that reason we will, first of all, close the feed regulating stems *E L E,* but otherwise allow the full boiler pressure to remain on the lubricator just as it was while feeding, with the water valve *D* wide open. Open drain stem *G* and allow all water from condenser *F* and the body of the lubricator to be blown out. After dry steam appears, close the water valve *D,* after which open all the feed regulating stems *E L E,* which will allow the water in each sight-feed chamber to be blown into the oil-feed chamber *d* with great force, cleansing the feed cones *1 1 1*, stems and oil tube *3* of all sediment. As a matter of fact the current of steam carries the water and sediment to the atmosphere through the drain stem *G.* Next, shut off the boiler pressure by closing steam valve *B* (it is not at all necessary to close the steam valve on the boiler). Then close the feed regulating stems *E L E* and drain stem *G,*

and remove the filler plug *O*. We now have a clean lubricator, but one as hot as the corresponding steam temperature could make it, and in order to reach this condition, which is the subject of Plate VI, we will consider that the locomotive is at rest, that the cylinder cocks or atmosphere valves are open, and that the air pump is closed down, so that any water which might find its way into the condenser *F* would be evaporated by the high temperature of the metal.

Plate No. VI shows sectional view of the Lubricator, with all chambers and passages blown out and, as shown by the views they now contain atmospheric pressure. In Plate V the lubricator is shown with the oil all fed out, and all parts and passages of the lubricator body and condenser which formerly contained oil were then occupied by water. The operation of preparing the lubricator for blowing out—preliminary to refilling it with oil—has been explained, and we now have a clean lubricator.

By referring to Plate VI, it will be seen that the feed regulating stems *E L E,* water valve *D,* drain stem *G* and steam valve *B* are all closed, and every portion and passageway of the lubricator, as well as the oil pipes to the air pump and steam chests, now contain atmospheric pressure. The filler plug *O* has been removed and the lubricator is now ready to be refilled with oil.

Plate No. VII shows sectional views of the lubricator filled with oil, but the reader will carefully note that the body of the lubricator is not absolutely full, for the reason that in filling the lubricator the level of the oil cannot rise above the point *g* of the filler hole without overflowing. The space above this point is an expansion chamber, and is one of the most important features in this

type of lubricator. This chamber was incorporated in the lubricator for the purpose of providing a space for the expansion of the oil when heated, thus relieving the body of the lubricator from the abnormal pressure exerted by expansion when filled with cold oil. This space or expansion chamber, at the same time prevents the oil from expanding back up through the water passage into the condenser, as it did in the old type of lubricators—especially those that had the filler hole so located that the body could be filled absolutely full of oil.

By referring to Plate VII, it will be noticed that atmospheric pressure occupies the oil tube 3, oil feed chamber *d* and the expansion chamber, as well as the condenser *F* and the sight feed chambers. If we should now turn on the steam pressure, or start the air pump, condensation would quickly gather in the condenser and sight feed chambers. At the same time, the steam circulating through the equalizing tubes would quickly heat the lubricator and oil to a temperature of about 60 degrees less than that of the corresponding steam pressure, and the oil would expand very rapidly, nearly filling the space occupied by the atmosphere. It is also true that the atmosphere has been expanded and occupies space that will be considered later.

In this instance (in a No. 21 Detroit lubricator, such as we are considering) the oil would have a space in which to expand equivalent to one-third pint of oil, and, if the water valve *D* was not immediately opened after steam was turned on, the expansion of the oil could do no harm.

The best authorities on oil agree that when taken at 32 degrees and heated to a temperature of say 200 pounds of steam, gauge pressure (387.6 degrees), the oil will expand not less than one-fifth of its volume or bulk; but

as valve oil of that temperature could not be put in a lubricator, some of this expansive force is spent or overcome by heating the oil to say 150 degrees before putting it into the lubricator.

If the reader wishes to carry out a little experiment he can do so by going to the oil room and procuring one pint U. S. measure, get the exact weight of it, then fill the measure with oil at about 70 degrees. He will find that the oil will weigh approximately 15 ounces. Now suppose that this pint of oil is placed on a stove and heated to a temperature of 150 degrees. He will find that in reaching this temperature the oil will have expanded and overflowed, yet the measure is absolutely full. Should he carefully wipe off the outside of the measure and reweigh the oil, it will be found to weigh but about 14 ounces, a loss of one ounce. The same thing is true in filling a No. 21 lubricator with cold oil. Its capacity is 42 ounces, but if hot oil be used (150 degrees temperature) 39 ounces, nearly will fill it, a difference in weight of three ounces. It will thus be seen that the expansion of 42 ounces of valve oil from 32 degrees to 387.6 degrees temperature will not be less than eight ounces, but if the oil is heated to about 150 degrees temperature before filling the lubricator its expansion will not exceed five ounces.

The natural inquiry is: "What becomes of the expanded oil if the lubricator has no expansion chamber?" The answer is simply this: When the water valve is open the expanding oil finds a natural relief through the water passage into the condenser, where it rises and floats on the water and is drawn down into the equalizing tubes by the current of the steam and carried to the air pump and cylinders.

The next question is: "How long will the oil continue to pass up through the water passage into the condenser?" It will flow until expansion has reached the limit, possibly ten minutes or more after steam pressure has been turned on the lubricator, and will continue to do so until the water has raised the oil above the lowest point of the water tube, when a natural water seal will be formed. Right at this point the writer wishes to call the attention of the reader to a most important fact, and that is that in the construction of the No. 21 lubricator no brass water tube is used, but instead a hole is drilled through the walls of the lubricator body, and through which the water is delivered at the lowest possible point in the oil reservoir. It is believed that the reader will now have a much better understanding of the conditions that appear mysterious to so many enginemen.

Plate No. VIII shows sectional views of the Lubricator in which the oil with which the oil reservoir *A* has been filled is now expanded.

Steam valve *B* has been opened and we now note that condensation has fully taken place, the expansion of the oil has been completed, and oil now occupies the expansion chamber, oil tube 3 and oil feed chamber *d*. Water occupies the condensing chamber *F* up to its highest point of condensation, and has also gathered in the bottom of the oil reservoir *A* and in the sight feeds, and is exerting hydrostatic force to all parts of the lubricator and feeds alike, but the reader will note that there is evidence of atmospheric pressure in the highest point of the expansion chamber, a trace of same in the oil tube *3*, oil feed chamber *d* and feed nozzles *1*, but this will quickly disappear after the feeds *E L E* have been opened, as every engineman knows from expe-

rience, and solid drops of oil will be fed until the lubricator runs empty.

Plate No. IX shows sectional views of the Lubricator in which the oil reservoir *A* has been drained.

In Plate VIII the lubricator is shown with the oil expanded and condensation having fully taken place, with a trace of atmospheric pressure in the expansion chamber, oil tube *3*, old feed chamber *d* and feed nozzles *1*, but as already explained, this atmospheric pressure would quickly disappear upon opening the feeds *E L E* and be followed by solid drops of oil.

In order that we may study another condition we will assume that the lubricator has again run empty, that is, that all the oil which was contained in the oil reservoir *A* has fed out. The water valve *D* and the feed regulating stems *E L E* are closed, but steam valve *B* remains open and full boiler pressure is on the surface of the water in condensing chamber *F* as well as on that contained in the sight feed chambers. (The writer here wishes to emphasize the fact that if the water valve *D* has an absolutely perfect seat the lubricator can be filled, regardless of whether the locomotive is working or at rest, or that full boiler pressure is on the condensing chamber *F*.)

Assuming that five minutes has been allowed for the lubricator to cool down, or that it is to be filled by the outgoing crew, this condition would be represented as shown in Plate V, from which the reader will see that condensation occupies every portion of the oil reservoir *A*, oil tube *3*, oil feed chamber *d* and the oil ways above the sight feed chambers, but he will also note that there is full boiler pressure on the surface of the water in condensing chamber *F* and in the sight feed chambers. In

order to again fill the lubricator with oil the condensation contained in the oil reservoir *A* must be drained off.

Plate IX shows the lubricator with oil reservoir drained, but it will be seen that the oil tube *3*, oil feed chamber *d* and oil ways above the sight feed chambers still contain water—in Plates VI and VII they contain atmospheric pressure, but this time it is water. It is desired to emphasize the fact that this is a condition common to all types of lubricators, as no provision has been made whereby this water can be drawn off. In fact there is no occasion to provide a drain to the feed chamber *d*, as when desired this chamber, as well as oil tube *3* and the sight feed chambers, may be blown out as explained in connection with Plate V, and thereby cleansed of all sediment they may contain. If the water valve *D* has a perfect seat, as before mentioned, the filler plug *O* may be removed and the oil reservoir *A* be again filled with oil.

Plate X shows sectional views of the Lubricator half filled with oil.

In order to fully explain another condition of the lubricator it will be necessary for the reader to refer to Plate IV, in which the oil reservoir is represented as being about half fed out.

To prepare the lubricator for the condition shown in Plate X, we will assume that the locomotive has reached a terminal and that all pressure and feeds have been closed off. The outgoing crew finds upon draining the lubricator that it contains oil. The reader will note by referring to Plate X that steam valve *B* and the oil feeds *E L E* have been closed. The water which was shown as occupying the lower half of the oil reservoir in Plate IV has been drawn off and the oil remaining in the reser-

voir now fills the space formerly occupied by the water, while the upper half of the oil reservoir contains atmospheric pressure. Note also that atmospheric pressure now fills the space above the water in condensing chamber *F* and the passage leading to the oil tube *R*.

By comparing Plates VII, IX and X together, it will be seen that in plate VII the oil tube *3* and oil feed chamber *d* contained atmospheric pressure, in Plate IX they contained water, but in Plate X they contain solid oil.

The lubricator as shown in Plate X is now in condition that the filler plug *O* may be removed and the reservoir refilled with oil, after which the pressure may be turned on and the feeds started.

Plate No. XI shows sectional views of the Lubricator with the oil feeding.

As will be noted, the lubricator has been refilled, full pressure has been turned on by means of the steam valve *B*, water valve *D* has been opened, as well as the oil feeds *E L E*, and the lubricator is now feeding solid oil. However, it is desired to again call the attention of the reader to the fact that atmospheric pressure occupies the highest point in the expansion chamber—just as it would in any other design of lubricator. As a matter of fact, atmospheric pressure is confined in all lubricators each time they are filled; it is simply impossible to avoid it. Now, let us see what the result will be.

We have noted that the instant the feeds *E L E* were open the drops of oil were solid—the hydrostatic pressure exciting a pressure equal to its weight on the lower side of the oil, and, the feeds being open, causes a downward current in the oil tube *3*, which permits the confined atmosphere to escape in the direction of the feeds

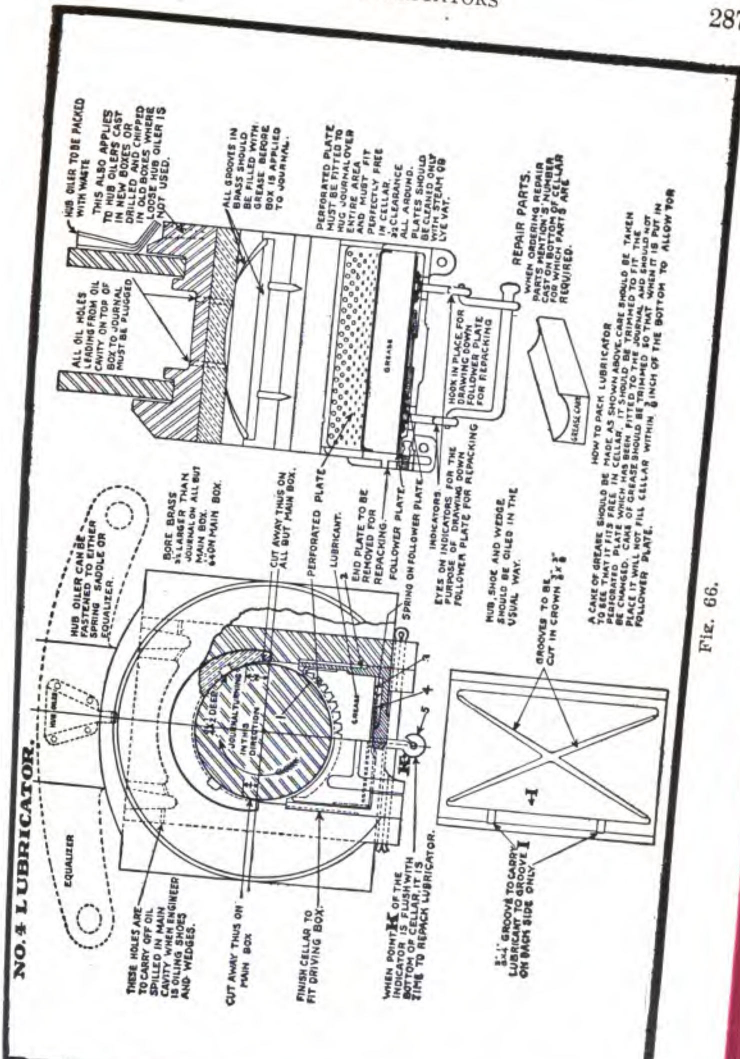

NO. 4 LUBRICATOR.
EQUALIZER
HUB OILER CAN BE FASTENED TO EITHER SPRING SADDLE OR EQUALIZER.
BORE BRASS LARGER THAN JOURNAL ON ALL BUT MAIN BOX.
THESE HOLES ARE TO CARRY OFF OIL SPILLED IN MAIN CAVITY WHEN ENGINEER IS OILING SHOES AND WEDGES.
CUT AWAY THUS ON MAIN BOX
FINISH CELLAR TO FIT DRIVING BOX.
WHEN POINT K OF THE INDICATOR IS FLUSH WITH BOTTOM OF CELLAR, IT IS TIME TO REPACK LUBRICATOR.
CUT AWAY THUS ON ALL BUT MAIN BOX.
PERFORATED PLATE
LUBRICANT.
END PLATE TO BE REMOVED FOR REPACKING.
FOLLOWER PLATE
SPRING ON FOLLOWER PLATE
EYES ON INDICATORS FOR THE PURPOSE OF DRAWING DOWN FOLLOWER PLATE FOR REPACKING
HUB, SHOE AND WEDGE SHOULD BE OILED IN THE USUAL WAY.
GROOVES TO BE CUT IN CROWN
GROOVE TO CARRY LUBRICANT TO GROOVE I ON BACK SIDE ONLY.
JOURNAL TURNING IN THIS DIRECTION
GREASE
HUB OILER TO BE PACKED WITH WASTE
THIS ALSO APPLIES TO HUB OILERS CAST IN NEW BOXES OR DRILLED AND CHIPPED IN OLD BOXES WHERE LOOSE HUB OILER IS NOT USED.
ALL OIL HOLES LEADING FROM OIL CAVITY ON TOP OF BOX TO JOURNAL MUST BE PLUGGED
ALL GROOVES IN BRASS SHOULD BE FILLED WITH GREASE BEFORE BOX IS APPLIED TO JOURNAL.
PERFORATED PLATE MUST BE FITTED TO HUG JOURNAL OVER ENTIRE AREA AND MUST FIT PERFECTLY FREE IN CELLAR. CLEARANCE ALL AROUND. PLATES SHOULD BE CLEANED ONLY WITH STEAM OR LYE VAT.
INDICATORS.
HOOK IN PLACE FOR DRAWING DOWN FOLLOWER PLATE FOR REPACKING
REPAIR PARTS.
WHEN ORDERING REPAIR PARTS MENTION 'S' NUMBER CAST ON BOTTOM OF CELLAR FOR WHICH PARTS ARE REQUIRED.
GREASE CAKE
HOW TO PACK LUBRICATOR
A CAKE OF GREASE SHOULD BE MADE AS SHOWN ABOVE. CARE SHOULD BE TAKEN TO SEE THAT IT FITS FREE IN CELLAR. IT SHOULD BE TRIMMED TO FIT THE PERFORATED PLATE WHICH HAS BEEN FITTED TO THE JOURNAL AND SHOULD NOT BE CHANGED. CAKE OF GREASE SHOULD BE TRIMMED SO THAT WHEN IT IS PUT IN PLACE IT WILL NOT FILL CELLAR WITHIN INCH OF THE BOTTOM TO ALLOW FOR FOLLOWER PLATE.

Fig. 66.

—possibly in five, ten or fifteen minutes, all depending on the rate of the feed. The engineman may be surprised to see that one or all of the feeds have apparently quit feeding. There is not a thing wrong with the lubricator, except that the confined atmosphere is escaping through the feeds, and as soon as that has been accomplished the oil will flow as it did in Plate IV. The reader should keep in mind this one fact, that oil and water, air and oil, or steam and oil have no affinity for each other; that is, they will not remain mixed long, but will separate at the earliest possible opportunity.

The accompanying illustrations, Figures 66 and 67, refer to the Franklin No. 4 Lubricator. It is claimed there are several hundred thousands of these lubricators for driving boxes now in use in this country and Canada. Therefore the illustrations, which are almost self-explanatory, may be found of interest.

When putting up this lubricator all the grooves in the brass should be filled with grease before applying the box to the journal. Perforated plates must then be fitted to hug the journal over its entire area and still be perfectly free in cellar. Cake of grease should be made to fit the cellar and perforated plate, care being taken that it be perfectly free in cellar. The following plate and spring will then hold the grease in contact with the perforated plate and journal. The indicator *K* on sheet No. 2523 will then show the amount of grease in cellar, and when the top of the eye at point *K* is even with the bottom of the cellar, there is still three-fourths of an inch of grease which will last for several days; the lubricator at that time should be reported for packing.

All oil holes on top of boxes must be plugged. The only oil which is necessary is on the hub shoes and

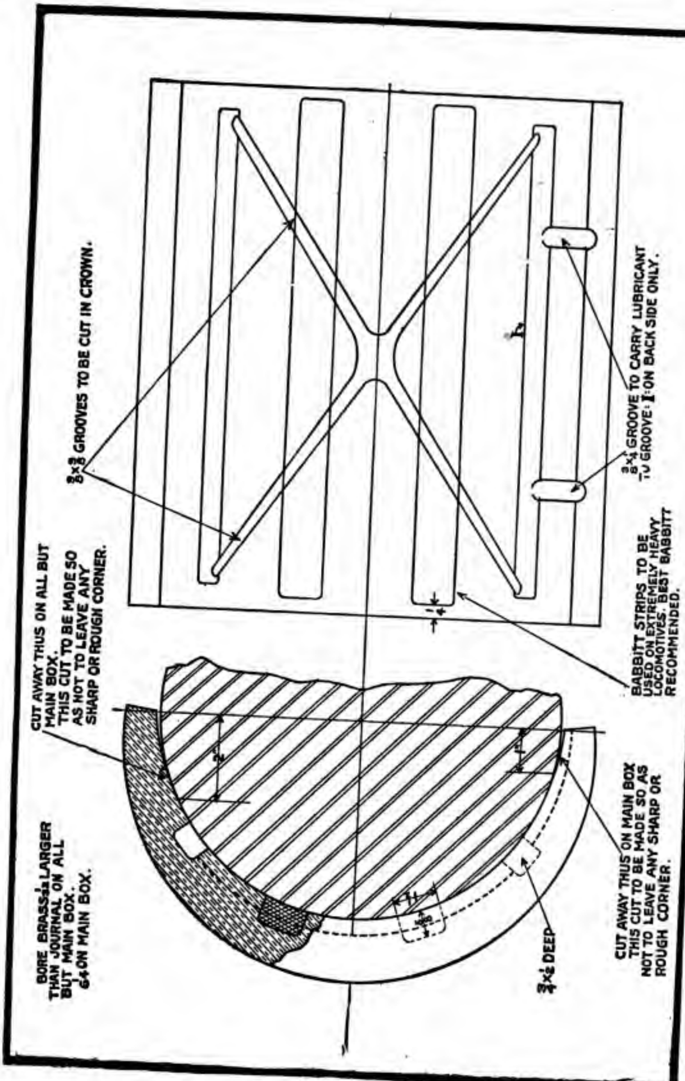

BORE BRASS 1/32 LARGER THAN JOURNAL ON ALL BUT MAIN BOX. 1/64 ON MAIN BOX.
CUT AWAY THUS ON ALL BUT MAIN BOX. THIS CUT TO BE MADE SO AS NOT TO LEAVE ANY SHARP OR ROUGH CORNER.
3/8×3/8 GROOVES TO BE CUT IN CROWN.
3/4×1/2 DEEP
CUT AWAY THUS ON MAIN BOX THIS CUT TO BE MADE SO AS NOT TO LEAVE ANY SHARP OR ROUGH CORNER.
BABBITT STRIPS TO BE USED ON EXTREMELY HEAVY LOCOMOTIVES. BEST BABBITT RECOMMENDED.
3/8×1/4 GROOVE TO CARRY LUBRICANT
1/16 GROOVE: I: ON BACK SIDE ONLY.

Fig. 67.

wedges. On blue print we show a hub oiler which can be fastened to either the spring saddle or the equalizer or an oiler cast in new boxes or drilled and chipped in old boxes as shown. These to be packed with wastes. This same method of oiling can be used on the shoes and wedges as shown on our print 4077. The temperature of the journal and box will be much higher than with oil, but there need be no alarm, however, if temperature should occasionally reach a point not to permit of holding the hand on end of axle. No injury whatever will occur to journal or box if indicators show a supply of compound in the lubricator. Under no circumstance should water be turned on driving box, although it may have reached what may be regarded as a high temperature. Water will develop serious difficulty by affecting the compound, causing it to quickly liquefy and run out of lubricator, leaving it empty or dry. In case of a driving box being considered very hot, the compound will take entire care of it until the end of the run much better than if it were possible to put oil packing or water around the box. Boxes found at a very high temperature should be reported at end of run for examination. Hub shoes and wedges should be oiled in the usual way.

LUBRICATORS AND LUBRICATION.

Question 1. What is a lubricator?

Answer. A cylinder-shaped reservoir for oil, which by the use of steam and water, pipes and valves, feeds oil regularly and automatically into the steam chests and cylinders.

Q. 2. About how long has the present kind of lubricator been in use?

A. Twenty years.

Q. 3. What device was used prior to that time to lubricate valves and cylinders?

A. Oil cups located on the boiler head in the cab. Oil was poured in the cups, and, the throttle being shut off and a valve opened that gave communication from the oil cup to the oil pipe, suction from the cylinders drew the oil down to them. The oil cup valve was then closed and the throttle opened. Prior to this time the cups were placed on the steam chests, where the fireman or engineer had to go to oil the valves. The closing of the throttle was very undesirable, as it had often to be done when the engine needed to exert all its power to haul its load.

Q. 4. Was the new device for lubricating valves and cylinders well received by enginemen at first introduction?

A. It was not. Many engineers claimed the old style cup was the best, as one drop of oil at a time was not sufficient to properly lubricate valves and cylinders. The fact that all the oil entering from the cups, except that

which adhered to the valves, valve seats and walls of the cylinders, was blown out of the stack and wasted, was not so generally known then as now. As a rule, where the lubricator was put on a locomotive the oil cups were left on so that the engineer could give the valves a good oiling every once in a while. In addition, oil was fed much faster through the lubricator feeds than necessary. Lubricators would be filled two and three times over a division, where now once filling it more than suffices. Even then the lubricators were a saving over the oil cups, and gradually but certainly the latter disappeared as the efficiency of the lubricators became better understood. The use of the auxiliary lubricator oil cups for a trip will satisfy any present-day engineer of how unsatisfactory was the old oil cups.

Q. 5. What are the essential parts of a lubricator?

A. The oil reservoir, with its filling and draining plugs, located respectively at top and bottom of oil reservoir; the oil-feed pipes and sight-feed glasses; the indicator glass to the oil reservoir; the condensing chamber placed above the oil reservoir and supplied with steam by a pipe connected to a globe valve, located on top of the boiler in the cab, and a valve called the water valve, used to shut off or furnish communication from the condensing chamber to the body of the lubricator and feed valves, located at bottom of sight-feed glasses. Then there are pipes used to convey the oil from the top of the sight-feed glasses to the valves, and called oil or tallow pipes from the fact that for a long time after the lubricators came into use melted tallow was used in them instead of the valve oil, now used.

Q. 6. On what principle do lubricators work?

A. That oil is lighter than water. That is, that the

oil will rise up through the water in the sight-feed glasses and pass out through the oil pipes to the valves and cylinders.

Q. 7. What is done when filling a lubricator with oil?

A. Shut off feed, steam and water valves. Open drain plug and drain out water in body of lubricator. Remove filling plug and close drain plug. Fill lubricator with clean oil, as any foreign substance will disarrange the feed. Replace filling plug. Open steam and water valves and, when desired, feed valves. A small air pocket is provided in the top of the lubricator to care for the expansion of the oil, which is considerable when cold oil is used, and even with this it is not best to fill the oil reservoir too full, as cases are on record where the bodies of lubricators have been bulged out and even split by the pressure of the oil under expansion. If lubricator is only filled moderately it may be necessary to wait a few moments until condensation takes place and raises the oil in the oil reservoir to the top of the feed pipes before the feeds will work. The natural expansion of the oil will also aid in doing this.

Q. 8. What is the use of the water valve?

A. To shut off, or supply the pressure to force the oil through the pipe to the feed valves and sight-feed glasses.

Q. 9. Where does the water that flows from the condensing chamber past the water valve go?

A. To the bottom of the oil cup, and as the oil overflows into the feed pipes at the top of the oil reservoir the water coming in at the bottom keeps the oil up level with the feed pipes until the supply is exhausted, when the lubricator must be drained and refilled.

Q. 10. What is used to prevent the oil feeding too

fast through the oil pipes, as it would if direct boiler pressure forced it out through a large opening?

A. Choke plugs, or plugs with very small tapering holes in them, through which the oil must pass before entering the oil pipes.

Q. 11. What might cause one side of a lubricator to feed faster than the other with the same feed-valve opening?

A. Less pressure in the chamber above sight glass on one side than on the other. This on account of equalizing tube being partly stopped up, or choke plug being badly worn so that steam from equalizing tube cannot maintain an equal pressure on the water in the glass and chamber above it.

Q. 12. Can oil get out of a lubricator in any other manner than through the feed valves?

A. Yes. A hole in the partition between the oil reservoir and condensing chamber, or a hole leading to a water passage above or below water valve would allow the oil to rise to the top of the condensing chamber and then flow through the equalizing tubes and escape through the oil pipes to the steam chests.

Q. 13. What causes a lubricator, from which only a portion of the oil has been used, to feed water?

A. A hole in the oil pipe leading to the chamber under the feed nipple, or a loose pipe which allows the water to enter it after the water has fed out to above the opening.

Q. 14. What often causes the feed on one side to stop working?

A. The choke plug becoming stopped up.

Q. 15. How can it be opened?

A. Close steam valve to lubricator steam pipe and

open drain plug a little. The open throttle and the pressure from the steam chests coming through the oil pipes will blow the obstruction from the choke plug. If this fails, disconnect oil pipe at lubricator union and run a fine wire through it.

Q. 16. In case choke plug cannot be opened, or feed will not work on account of a broken feed glass or other cause, what can be done?

A. The valves and cylinders can be oiled through the auxiliary oil cups on the lubricator.

Q. 17. How can a sight-feed glass that has become filled with sediment be cleaned out without removing the glass, where no plug is provided at bottom of glass for draining out the water in it?

A. Close water valve, leaving feed valve well open on glass to be cleaned. Open drain plug, when water and sediment in the glass will be drawn out into the body of the lubricator.

Q. 18. What is the result if the pressure on the oil pipes is the greatest at the lubricator end?

A. The pressure of the steam and the gravity of the oil carries it to the steam chests.

Q. 19. If the pressure is greatest at the steam chest end of the oil pipes, what is the result?

A. The pipes become filled with water. The oil ceases to feed into the steam chests and the valves and cylinders become dry. This condition can only be overcome by reducing the pressure on the steam chest end of the oil pipes by easing off or closing the throttle for a brief period of time, when the oil and water held in the pipes will pass to the valves and cylinders. On runs where long distances are made without stopping, it is a good practice to nearly or quite close the throttle occa-

sionally so that the oil held in the pipes may pass to the valves and cylinders.

Q. 20. Does oil pass to the steam chests in the same condition that it appears to be in when passing through sight-feed glasses?

A. No! When it gets to opening in choke plugs it is atomized by mixture with water under pressure, and in that condition it goes to the valves, so that they are fed both oil and water by the lubricator.

Q. 21. What is done in case a sight-feed or indicator glass breaks?

A. Close all valves. Remove plug at top of glass and the packing nuts. Put new gaskets in packing nuts in place of old ones and start nuts on packing boxes. Put glass in from top where plug was removed and force it down on its seat with a round stick. Tighten packing nuts and replace plugs, open all valves and lubricator is ready to feed. Some lubricators are provided with check valves that shut off lubricator automatically when a glass breaks.

Q. 22. Is it possible to tell when valves and cylinders are not receiving enough oil?

A. Yes; dry valves will cause valve stems to buckle and reach rod to rattle, and lever will handle hard. Cylinders run short of oil will groan dismally, and if let go too long will cut, as will a valve.

Q. 23. Is it possible to tell when too much oil is being used?

A. Only by experimenting to find out the least amount that will lubricate the valves and cylinders properly.

Q. 24. What first led to the agitation for oil economy?

A. The waste of oil by its too free use.

Q. 25. Have the restrictions as to the use of oil as a whole been beneficial from an economical standpoint?

A. Yes; in some instances oil economy has been carried to such an extent as to waste coal and damage valves and cylinders; in such cases it has been an expense and not a saving.

Q. 26. Does the present high steam pressure have any effect on valve lubrication?

A. Yes; more oil is required to properly lubricate the valves of a high steam pressure engine than of a low steam pressure engine. The degree of hardness of the valves and valve seats also has much to do with the amount of oil the valves may require.

Q. 27. Is sufficient oil usually allowed to the air pump in computing oil mileage?

A. No; with the long train lines now in use the pump has much work to do, and it is given oil in excess of the amount it is supposed to have that is charged to the valves and cylinders on the performance sheet.

Q. 28. Does the weight and speed of the train have any effect on valve and cylinder lubrication?

A. Yes; the faster the speed with the same train, or the heavier the train at the same rate of speed, more oil will be required in a given time, as the locomotive is doing more work in the same period.

Q. 29. Does the condensation of water in the cylinders or the working of water in them have any bad effect on valve or cylinder lubrication?

A. It does have a bad effect, the water being hot washes the oil away that would otherwise cling to the valve seats and cylinder walls, and it escapes unused through the cylinder cocks and smokestack.

Q. 30. What effect has dry valves on the fuel consumption of a locomotive?

A. It increases it materially on account of the in-

crease of friction between the valves and valve seats. Start a light engine with dry valves at a good speed, and shut off steam and note how quickly the engine will stop. Oil the valves well, repeat the experiment and note how much farther the engine will run before stopping.

Q. 31. Does the piston valve require less oil than the slide valve?

A. Yes; but it will not give warning that it needs more oil like the slide valve will when dry. The reach rod will not rattle or the reverse lever handle hard, and for that reason it may run dry and receive excessive wear unnoticed.

Q. 32. Can any set number of drops of oil per minute be decided on as the amount a lubricator should feed?

A. No; the amount of work the locomotive is doing must determine the amount of oil that it receives. The tendency is to rate the amount of oil allowed engines too low, particularly on local freight and switch engines.

*CATECHISM ON LUBRICATION.

Question 33. What is friction?

Answer. It is resistance that a bearing receives from another bearing over or about which it works.

Q. 34. What are the direct results of friction?

A. Heat and wear.

Q. 35. How are these to a large extent offset?

A. By lubrication.

Q. 36. What is lubrication?

A. It is the introduction of a viscid foreign substance between the surfaces of two metal bearings for the purpose of reducing the friction and consequent wear and heat to the lowest possible degree.

Q. 37. What is the action of the lubricant?

A. It serves to keep the two surfaces apart by the adhesion of the lubricant in a thin sheet or film to the adjacent parts. While the layer of lubricant is of necessity very thin, yet it is thick enough to give the desired result. A good object lesson of this fact is shown when the lubrication between a cross-head and a guide bar becomes deficient. The bar will heat, become very bright from wear, and, if there is much dust, its surface will cut.

Q. 38. How is friction reduced in another manner?

A. By having the surfaces of bearings as hard and smooth as possible where it is permissible, as in guides and links.

Q. 39. Why does the wear and heat itself increase when the bearing becomes hot?

*W. L. French.

A. Because with heat comes expansion, causing the bearing parts to work tighter, thus increasing the friction and heat. The wear is also greater on account of the heat, as heat softens a metal.

Q. 40. In the selection of a lubricant for a bearing what must be considered?

A. The amount of frictional or other heat to which the part is subjected. For this reason, engine or car oil, which will stand about 300 degrees of heat before igniting, is used for car boxes, tank and engine truck boxes, driving cellars, eccentrics, links and similar bearings, while valve oil, that will burn at about 500 degrees heat, is used for valves, cylinders and air pumps. When a box becomes hot where grease is not used, the use of car or engine oil should be discontinued and valve oil used. If possible, cool the box down before applying oil at all. To pour engine oil on a hot box without cooling it down to a normal temperature is only adding fuel to the flames.

Q. 41. When a box or bearing heats, what is the first thing to note?

A. See if it has been getting the oil intended for it, and if any unusual condition has caused it to heat. As a rule these troubles occur at a time when minutes are of value and there is no time to waste on them. If oil has not been reaching the bearing in sufficient quantity, the fault should be remedied and a more liberal supply given until conditions are normal.

Q. 42. If an engine truck journal, tank truck journal or driving journal became too hot, what should be done to remedy it?

A. If engine is equipped with water pipes for the purpose, turn the water on, being sure to have the box re-

packed at the terminal. If not, and the box is not too hot, a liberal supply of valve oil often repeated will generally fix the box so it can be run in to the terminal. If necessary to pack the box, cool it down thoroughly before so doing. If it is a driving cellar that is behind the eccentrics it can only be run in; even at a slower rate of speed less time will be lost than to pack it, even if possible, on the road. By cooling it down occasionally and giving it a free supply of valve oil, one can usually go along in good shape. A hot eccentric can be run at a high rate of speed if oiled liberally with valve oil for a few miles, and unless there is something out of the ordinary the matter it will cool down. It is best to leave eccentric straps open unless they have been recently closed and are heating on account of being too tight. If they have been running good, a stopped up oil hole or some foreign substance between the eccentric and straps will generally be the cause of the trouble. Sometimes a brass is allowed to remain in a tank truck or engine truck oil box until it is too thin and causes the box to heat, or it may split and cut the journal and require renewing on the road. It is better to have these changes made before the trouble occurs, as practical experience will tell an engineer when a brass has been worn to about the limit of thinness. A driving brass worn too thin will give trouble until it is replaced with a heavy one. The speed of the train on which an engine is employed has a bearing also on these matters.

Q. 43. In replacing a box, what care should be exercised?

A. See that the packing is thoroughly saturated with oil. That it is pushed to the back of the box so as to lubricate the rear of the journal. That the packing is

not put into the box so tight as to force out the oil and make the packing hard and dry. It should fill the box loosely, care being taken that it comes up well to the journal. Care of these things before going out will save much annoyance and delay on the road. It is not always the great amount of oil used, but the fact that what is used is applied at the proper time and in the proper place and manner that counts.

Q. 44. To insure the oil reaching the bearings in very cold weather, what must be done?

A. Oil holes should be opened frequently, and the average engine oil must be thinned with kerosene, else it will not lubricate until a bearing heats and warms it, causing it to feed. The oil in a hand oiler that has recently been taken from the boiler head will become too thick to use in very cold weather before the engineer gets around his engine if the oil is not thinned with kerosene. In the summer, the hand oiler should be carried some other place besides the boiler head, as it then becomes too hot and runs off the bearing with but little benefit as a lubricant.

Q. 45. What lubricant besides oil is used on crank pins and journal bearings?

A. Grease, or, as it is sometimes termed, hard oil.

Q. 46. How is it applied to crank pins?

A. A large, hollow cup is attached to the top side of the rod strap. A small hole leads from the bottom of the cup down through the strap to the pin. The inner side of this cup is threaded to fit a plug that is screwed down on the grease within the cup, forcing it down on the pin until the supply within the cup is exhausted. A turn, or a little more than a turn, is usually sufficient to run a pin an ordinary trip under normal conditions.

Q. 47. If grease is forced down too hard on a pin, what bad effects will it have?

A. It tends to increase friction and heat, and the grease is forced out around the collar of the pin and the hub of the wheel and is largely wasted; the cost of lubrication is thus increased. Experience will tell the engineer when the grease under the plug feels firm enough to indicate that sufficient pressure has been applied to it, and that it is time to quit forcing the plug down.

Q. 48. Will pins run warmer with grease than with oil as a lubricant?

A. Yes; partly owing to the grease causing a little more friction, and partly owing to the fact that it does not commence to lubricate until slightly warmed. There is practically no danger of throwing the babbit or cutting a pin if grease is kept on the bearing, but of course more will be used.

Q. 49. Has a hard rain storm any effect on the amount of grease needed by a crank pin?

A. Yes. It washes away from around the collars, and the plugs will need to be screwed down more often than ordinarily.

Q. 50. Is it necessary or advisable to use water on a crank pin equipped with a grease cup?

A. No. It washes the lubricant away. Oil should not be used, either, as the grease is capable of meeting all requirements, if properly supplied.

Q. 51. Is grease found to be a satisfactory lubricant on the crank pins of large locomotives?

A. Yes. Owing to their large frictional surface and the heat and dust to which they were exposed, oil was a very unsatisfactory lubricant for crank pins, but grease,

owing to its remaining on the pins even at a high temperature, lubricates them and reduces the amount of failures from hot pins.

Q. 52. How is grease applied to driving journals?

A. A plate is used in the driving cellar, called a follower plate. Between this plate and the bottom of the cellar a spring is located that crowds the follower plate upwards. The grease is placed on top of the follower plate in strips the length of the journal bearing, and as the grease is worn away by the revolving journal the spring pushes it up until the supply is exhausted.

The strips of grease do not come in direct contact with the journal, but the grease is forced through a perforated plate at the top of the cellar to the journal.

Q. 53. How is it known when the supply of grease in a cellar has been exhausted?

A. By two indicators fastened to the follower plates and extending down through the bottom of the cellar. They are located one near each end of the cellar. When the rings at the lower end of the indicators are up to the bottom of the cellar it is time to repack it.

Q. 54. Should an engineer note the condition of grease cellars before going out on a trip?

A. Yes. While it ought not to be necessary for him to do so, yet it may save him a great deal of bother later on. A cellar runs a good many thousand miles with one filling, so the indicators do not need to show much in the cellar in order for it to contain enough to make one trip.

Q. 55. Can a driving cellar be packed with grease on the road?

A. It can. Remove plate on front of cellar. Pull in-

dicators down and fasten them. This will bring follower plate down so that strips of grease equal to the length of the journal bearing can be laid on it. Put side strips in first and fill the center. Replace end plate and release indicators. Grease for cellars is harder than that used in rod cups. A supply on an engine for emergencies is a good thing to have.

Q. 56. Is any change made in the driving box where grease is used in the driving cellars instead of waste and oil?

A. Yes. Several changes are made. There is no oil hole in the top of the box or bearing, or grooves in the latter, but slots are cut in the sides of the bearing.

Q. 57. What advantage is found where grease is used in driving cellars?

A. The lubricant is always up to the journal as long as there is any in the cellar, while waste packing would settle away from the journal at times and cause trouble before the fact was discovered. The grease remains on the journal and lubricates it even at a high temperature.

Q. 58. Has grease been tried as a lubricant on any other parts of a locomotive besides boxes and crank pins?

A. Yes. Some roads have tried it with indifferent success on the boxes of trailing wheels and engine trucks.

Q. 59. What have tests with grease shown?

A. That where grease is used, the friction resistance is considerably higher than where oil is used.

Q. 60. Is the cost of grease per hundred miles run greater than the cost of oil?

A. There is practically no difference in the first cost, but the extra friction where grease is used causes greater

wear and a consequent earlier renewal of bearings, as well as a slightly increased fuel consumption.

Q. 61. What offsets this?

A. Less engine failures and more satisfactory results to everybody concerned. It is doubtful if its use will be extended beyond crank pins and driving journals, as on them alone has it shown the best results.

SETTING LOCOMOTIVE VALVES.

Setting the valves of a locomotive is nothing more or less than setting the valves of four ordinary slide-valve stationary engines, two to run in one direction and two to run in another or opposite direction, Mr. D. B. Dixon states in his reference book, and he says: "It is true, an obstacle to easy and quick setting exists in the locomotive not usually found in a stationary engine—namely, the *link.*

"There are four stages in the career of a slide-valve and piston while making one stroke; they are:

"*Admission* of steam to the cylinder.

"*Cut-off* of steam from the cylinder.

"*Release* of steam from the cylinder.

"*Compression* of steam in the cylinder by reason of exhaust closing before the piston reaches the end of the stroke.

"Cutting off short means exhausting too early, and there is a limit to the point of cut-off where economy is an object.

"*Shifting Link.*—With a shifting link the lead of the valve increases as the reverse lever is hooked back, or as expansion increases, and a valve to which no lead is given when it is set will gain about 3-32 of an inch when the lever is hooked back into the 3-inch notch.

"*Stationary Link.*—With a stationary link, where a radius-bar is used to connect the link-block to the lower rocker-arm, the lead never changes; it is constant at any point of cut-off.

"The reason why a shifting link changes the lead and a fixed link does not is owing to the angularity of the eccentric-rods changing by shifting the link, as any one can determine for himself by shifting the link to cut off at, say, 6 inches, and then, the engine being in the forward motion, disconnect the go-ahead eccentric-rod and lower it with the eccentric in different positions; he will notice that as the lever is hooked back he must move the rocker-arm more or less in order to again make the connection. Moving the rocker-arm necessarily moves the valve; moving the valve alters the lead. With a fixed link the angularity of the rods is the same always, as the link is not raised or lowered. The reader can make a pencil sketch to illustrate this.

"Should the valves not come square, the fault may lie in the point of suspension of the link; or the reverse shaft may be too close to, or too distant from the rocker-shaft; or the reverse-shaft lifters may not be of equal length, or one may be higher or lower than the other, or both too high or too low; or the reach-rod may be too long or too short; or the link may not be an arc true to its proper radius."

"Throw of Eccentric.—The throw of the eccentric of a stationary engine is equal to twice the lap on the valve, added to twice the width of steam-port; but with a locomotive this will not be sufficient, owing to cutting off with the link. To illustrate, we will take a valve-seat 10½ inches long, steam-ports 1¼ inches long, exhaust-port 2½ inches long, bridges 1 inch long; valve 8½ inches long, valve cavity 4½ inches long; throw of eccentric 5 inches; end travel of valve 5 inches; lap on valve ¾ inch; lead nothing.

Note. In giving valve-seat dimensions the length of

seat, bridges, and ports is assumed to be in the direction of motion of the engine, and *not* in the direction of cross section of cylinder.

"Now, in order to give a full port opening, with the link in full gear, the stroke of the valve need not be more than 4 inches—that is, twice the lap=1½ inches, twice the width of steam-port=2½ inches; but in working expansively, with the lever hooked back into the last cut-off notch, the valve would not have travel enough to give a steam-port opening with a 4-inch throw of eccentric, consequently we must increase the travel in full gear more than is necessary in order to get a port opening when cutting off short. In order to do this we give the eccentric 1 inch more throw, or 5 inches instead of 4, and make the valve travel half an inch past the inside edge of the steam-port when the link is in full gear.

In cutting off short the exhaust opens too soon and releases the steam before it has done its full duty; this could be remedied by shortening the exhaust cavity of the valve, or, in other words, giving plenty of inside lap. But here another difficulty springs up; if we give inside lap to delay the exhaust opening on one end of valve we close the exhaust too soon at the other end, and perhaps give no exhaust opening at all if cutting off at the shortest point. This goes to show that the link is far from being a perfect device for working steam expansively. An early cut-off and a too early release of the steam do not appear to be true economy, yet the majority of locomotives are now running under these conditions.

Saddle-Pin.—The saddle-pin centre is not usually placed where it would seem naturally to belong—that is, directly over the arc of the link—but it is placed outside

the chord of the arc in most links. The purpose of this is to counteract the slip of the link. In a standard passenger engine link the writer observed it to be placed 29-32 of an inch back of the arc of the link and in a standard freight link ⅝ of an inch back.

Line of Centers.—In link-motion much is gained by preserving as far as possible a line of centres. For this reason, in the link before mentioned, the centre of saddle-pin is placed several inches above its natural position, or at such point as would bring the centre of eccentric-rod pin, and the centre of link-block, and centre of saddle-pin as near to each other as possible. By raising the saddle-pin as described, its centre and that of the link-block are brought in line, and knuckling of the link is in a great measure avoided while the reverse-lever is in the cut-off notch in which it is most generally carried.

Length of Link.—The length of link is not governed by the space under the boiler for raising it, but by the travel of valve; as should the link be made too long, and the sector notched accordingly, in full gear the valve would travel off its seat, supposing the seat to be properly proportioned. But should the link be too long, and the sector notched for a link of proper length, the valve would travel all right.

Travel of Valve.—The travel of a slide-valve and the *stroke of a slide-valve* mean one and the same thing, although if spoken of with reference to the stroke of the piston the *travel* of the valve might be said to commence with the piston just finishing its stroke, or, if no lead is given to the valve, just as the piston has finished its stroke.

Suppose a valve of dimensions already given—that is, length of valve, 8½ inches; length of cavity of valve, 4½

inches; lap, 3/4 of an inch; no lead. Valve-seat, 10 1/2 inches long; length of steam-ports, 1 1/4 inches; length of bridges, 1 inch; length of exhaust-port, 2 1/2 inches; length of seat-faces, 1 3/4 inches; travel of valve, equal to throw of eccentric, 5 inches. Now, when the crank is on its dead-centre, and the piston at the end of the cylinder, or end of its stroke, the end of the valve is at the outside edge of the steam-port. The piston begins to move towards the other end of the cylinder; at the same time the valve begins to move in the same direction, and continues moving until the end just referred to reaches the middle of the bridge, when it begins its return movement. The valve has now traveled 1 3/4 inches. Continuing its return movement (the piston is still going in the direction in which it started), it advances until it arrives at a point 3 1/4 inches from the middle of the bridge. At this instant the other end of the valve is at the outer edge of the opposite steam-port, *and the piston has completed its stroke.* The valve still keeps moving on its return until the end reaches a point 5 inches from the middle of the bridge first referred to, when the opposite end of valve is in the middle of the opposite bridge and the travel is completed. The first part of this valve movement might properly be called "travel," and the last part "stroke."

Let the reader take two pine sticks, make a valve and seat according to dimensions given, and get a practical illustration of valve travel and stroke as here described.

The Eccentric.—An eccentric is but another form of crank, and its function is the same—that is, to give a backward and forward motion, or a *reciprocating* motion, properly speaking. If we make an eccentric of 5-inch throw we simply make a crank, the distance between

the centre of the axle or shaft bore of which and its wrist-pin bore is 2½ inches. Such crank would give a 5-inch stroke; such eccentric gives just the same stroke —that is, 5 inches. The difference between the two is that the eccentric can be used on a locomotive axle or engine shaft when the crank cannot, otherwise the crank might very often take the place of an eccentric so far as cheapness is concerned.

The eccentric is "eccentric" by the amount that the centre of the axle or shaft bore is distant from the centre of the eccentric.. If these centres are 2¼ inches apart the eccentric has a 4½-inch throw; if 2½ inches or 2¾ inches apart, the eccentric has a 5-inch or a 5½-inch throw, and so on.

Cam.—A cam and an eccentric should not be confounded together, as their motions are not precisely the same, and it is as improper to call a cam an eccentric as to call an eccentric a cam.

Inclined Cylinders.—Some locomotives have inclined cylinders. When such is the case, and the valve-seat inclines also, or when the valve-seat and the longitudinal axis of the cylinder are in the same plane, but at an angle with the frame, the lower rocker-arm must be set back in order to connect the link to the eccentric-rods, and that the end travel of the valve may be the same for both ends of the valve.

If the cylinders incline, and the valve-seat be made horizontal or parallel with the frame, the arm need not be set back. Cylinders with the bore and valve-seat at an angle are sometimes put on locomotives. In the case given above, lengthening the eccentric-rods would not do, although it would enable a connection to be made with the link.

Angularity of Eccentric-Rods.—The motion of a link is quite complicated, owing to the many and different angles made by the eccentric rods with the plane of motion of the driving axles, and with each other, during one revolution of the eccentrics, and can be best studied by observation, as most book explanations make "confusion worse confounded" to the novice in mechanics.

Angularity of Main Rods.—The different angles formed by the main rods with the crank while the latter is making one revolution is another source of trouble in determining relative positions of piston and valve, or of two pistons, of an engine. If we set the crank plumb the piston will not be in the middle of its stroke; if the crank-pin is above the axle the piston will be past the middle of the stroke, so also if it is below, as the main rod is the hypothenuse of a right-angled triangle, and consequently the longest side of the triangle formed by the rod, the crank, and the axis of the cylinder, or the plane of motion of the centre of the axle. If we disconnect the crank-pin end of the rod, and drop it down to the centre of axle, we will find that the centre of the brasses is beyond the axle-centre; and now if we move the piston into the middle of its stroke, and raise the rod to make connection with the crank-pin, we will find that we cannot do it, as the end of the rod will not reach the pin.

Let the reader take a pencil and paper and draw sketches showing the crank plumb, and also at different angles, and note the position of the piston while those angles are being formed, with the crank-pin above the axle and with the pin below the axle. He will find a great difference in the relative positions of crank and piston."

THROW OF ECCENTRIC.

How to get the throw of eccentric, or travel of valve:

RULE.—It is found by adding together the width of both steam-ports, and the lap on both ends of the valve; this product will give the exact opening of steam-port, about ¾ inch more being added to the above product so that the edges of the valve will travel about a quarter of an inch beyond the inside edge of steam-port, on the bridge, which is termed over-travel and gives more opening of port when working in back notches.

EXAMPLE.

Width of front port	1¼	inch.
Width of back port	1¼	inch.
Lap of front end	1	inch.
Lap of back end	1	inch.
Over-travel	¾	inch.
Total travel of valve	5¼	inches.

DIRECT AND INDIRECT MOTION.

(See Figs. 68 and 69.)

Fig. 68 is indirect motion, the rock-shaft being used. This link motion is in general use in the United States. *A*, the crank-pin, on the back center. *B*, the full throw of forward eccentric, which follows the crank. *C*, the full throw of back motion eccentric, which leads the crank when the engine is moving forward. *D*, the eccen-

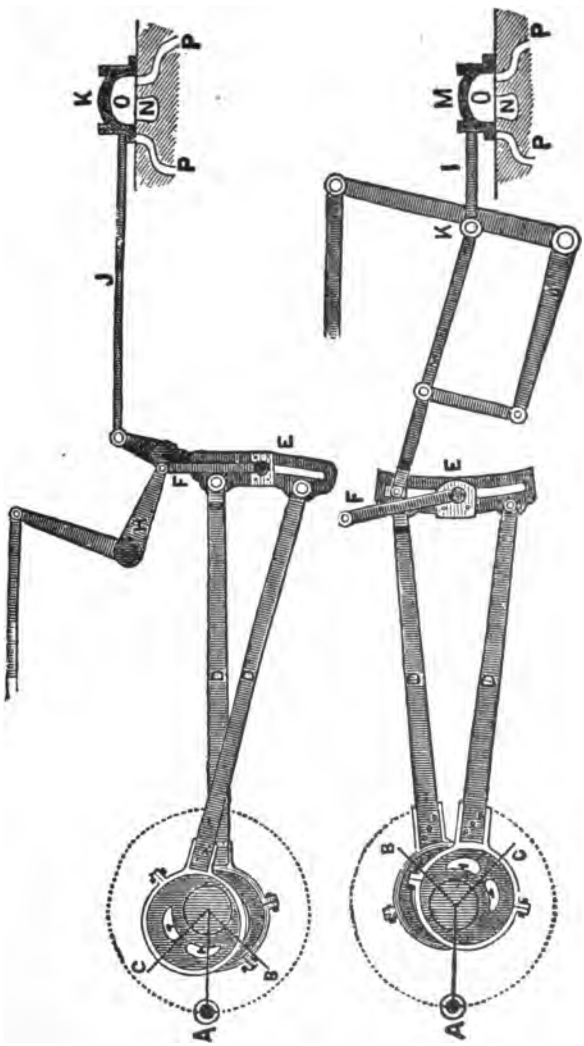


Figure 68. Indirect Motion.—Figure 69. Direct Motion.

tric-rods. *E,* the link. *F,* link-hanger. *H,* lifting-shaft. *I,* rocker-shaft. *J,* the valve-rod. *K,* showing the valve on lead-line on back steam-port. *O,* throat of valve. *N,* exhaust port. *P,* steam-ports.

Fig. 69 is direct motion, the valve-rod taking hold of link-blocks by means of a fork-end valve-rod. *A,* the crank-pin, on back center. *B,* the full throw of forward eccentric, which leads the crank-pin. (It will be observed that the full throw of eccentric is right the reverse of that shown on Fig. 69. *C,* the full throw of back motion eccentric, which is also reverse to that shown by Fig. 68; still the valve is on the lead-line at the same end of cylinder, the rocker-shaft causing this change of position of eccentrics, as it is plainly seen, when using the rock-shaft; if the full throw of eccentrics be moved forward, to the same position as shown by Fig. 69, then the lower rocker-arm would be forward, and the upper arm of rocker would be moved back, and the lead-line would be given to the front steam-port, instead of the back port; not like the direct motion, when the full throw of eccentrics moves forward the valve moves forward also; consequently, when the rocker is used, the eccentrics must be placed right to the reverse of direct motion to give the opening of steam-port to right end of cylinder. *D,* eccentric-rods. *E,* link. *F,* hanger. *H,* fork-end of valve-rod. *I,* valve-rod. *J,* lifting-shaft. *K,* knuckle-joint centers of valve-rod. *L,* lifter. *M,* valve, showing lead on back steam-port.

TABLES OF LINK MOTION.

Valve tables of link motion, showing the different effects produced in the distribution of steam, with different laps, leads, travel of valves, and points of suspension, or locating the centre of stud on saddle.

Table No. 1, of link motion, was taken from an engine cylinder 15 inches in diameter; stroke 24 inches; valve having no lap; face of valve being the total length between the extreme outside edges of steam-ports; the width of exhaust cavity, or throat of valve being just the width of extreme distance of inner edges of steam-ports; throw of eccentric 4 inches; lead given, in full stroke, ⅛ inch; rocker-shaft is used; position of eccentrics being nearly at the right angle to the crank-pin. If there was no lead in consideration, then the full throw of eccentric would be just at right angles to the crank-pin, or one-quarter of the circle from the crank-pin; therefore, with this valve, as the table shows, the valve is in the middle of its stroke when the piston is at the end of its stroke, and the valve closes both the steam and exhaust passages, and is ready, with the slightest possible advance, to open both for the return stroke of the piston. In referring to the table, we find, when cutting-off at any point of the stroke, that the steam will be admitted to the opposite side of piston at the same time; and, when cutting-off at half stroke, the link block will be in the centre of link, and the valve will be in the middle of its stroke, cutting off the steam from one end of the cylinder, when the valve will be just opening to admit steam in the other end of cylinder. The table shows that, when

VALVE TABLE OF LINK MOTION—NO. I.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins,		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	100	4	$2\frac{1}{16}$	2	24	24	24	24	24	24	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{8}$	0
2	79	$\frac{13}{16}$	$\frac{1}{2}$	$\frac{7}{16}$	19	19	19	19	19	19	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{11}{32}$	5
3	71	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	17	17	17	17	17	17	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	7
4	62	$\frac{11}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	15	$15\frac{1}{4}$	15	$15\frac{1}{4}$	15	$15\frac{1}{4}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{3}{32}$	9
5	50	$\frac{5}{8}$	$\frac{9}{32}$	$\frac{9}{32}$	12	12	12	12	12	12	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{32}$	12

Table of Link Motion, taken from an Engine cylinder, 15 inches diameter; stroke 24 inches; steam-ports 14x1$\frac{1}{8}$ inches; exhaust ports 14x2$\frac{1}{4}$ inches; throw of eccentric 4 inches; lead $\frac{1}{8}$ inch, in full stroke; stud on saddle 5-32 back of centre line of link, towards axle; valve having no outside or inside lap, the length of valve face being the total length between the extreme outside edges of steam ports; the width of exhaust cavity, or throat of valve, being just the width of distance between the inner edges of steam port; rocker-shaft being used.

the steam is cut off at half stroke, or any other point of stroke, the exhaust opens at the same time, for the same end of cylinder, and the exhaust closes, and steam is admitted in the opposite end of cylinder all at the same time; therefore, without lap we have admission, expansion, release, or exhausting, and compression, all taking place at the same time; therefore, it becomes necessary to make the valve longer, so as to lap over the steam-ports at both ends, when in the middle of the stroke. By increasing the lead, it would give an earlier release, or, in other words, the exhaust will take place sooner; this will bring another difficulty, in the shape of premature or too early lead, for the same distance from end of stroke that release or exhaust takes place on one end of cylinder, lead would take place the same distance from the other end of cylinder. It is plainly seen that a valve without lap cannot be used for the locomotive, when using the single valve, as the exhaust or release does not take place at the right time, as it takes place at the end of stroke, and there is no time for the exhaust to take place prior to the end of stroke, and the steam cannot be worked expansively, without lap, for the expansion of steam in the cylinders takes place during the intervals between the suppression and release of the steam admitted to the cylinder. Lap of valve provides expansive action of the steam; for this object lap is given. Without lap, when using the common D, or slide valve, there can be no expansion, as the table shows, because then the suppression and the release of steam admitted to one end of cylinder, occurs at the same time. There is no difficulty in getting steam into the cylinders, as the steam rushes in, corresponding with the travel of piston. After the steam has exerted its force, it is then required to have

a free and rapid departure, by having a wide passage before the piston has reached the end of its stroke.

TABLE NO. 2.—In referring to this table we find what may be called a short lap valve, as the lap is much shorter than is used in a locomotive with link motion, it being a ⅜th lap valve, having ⅜-inch on each end, the length of valve-face being ¾ of an inch longer than the extreme distance between the outside edges of steam-ports, the inside having no lap, the throat or cavity of valve being the same width as the distance between the inner edges of steam-ports; lead 1-16-inch in full stroke, rock shaft being used; diameter of cylinder, 15 inches; stroke, 24 inches; throw of eccentric, 4 inches, being the same motion as Table No. 1, except the increase of lap. In referring to tables, we find a very different motion, as Table No. 2 shows that we have gained the position required for the valve for admission of steam, for all the notches, nearly to half stroke; we also find a decided improvement toward working the steam expansively, as the table shows, from the fourth to the eighth notch. That twenty-five per cent of the distance that the steam follows the piston is worked expansively, from the fourth to the eighth notch. We also find the same difficulty as that shown in Table No. 1, by premature or too early lead, as we find, by referring to Table, that lead commences 1⅛ inches from end of stroke, when working in the fourth notch, and 1½ inches from end of stroke, when cutting off at half-stroke, or working in the sixth notch; and when working in the eighth notch, or cutting off at 8 inches, one-third of the stroke, we find lead takes place 3 inches from end of stroke, causing a counter-pressure that would be a difficult matter to overcome, without the increasing of lap, when giving lead for the full-stroke notch.

VALVE TABLE OF LINK MOTION.—NO. II.

Notches.	Per cent of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	95	4	$1\frac{11}{16}$	$1\frac{5}{8}$	$22\frac{7}{8}$	23	$23\frac{5}{8}$	$23\frac{3}{4}$	$23\frac{5}{8}$	$23\frac{3}{4}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{5}{8}$	0
2	79	$2\frac{1}{4}$	$\frac{3}{4}$	$\frac{11}{16}$	19	$19\frac{1}{8}$	22	22	22	22	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{1}{4}$
3	71	$1\frac{7}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	17	17	$20\frac{7}{8}$	$20\frac{7}{8}$	$20\frac{7}{8}$	$20\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{32}$	$\frac{1}{2}$
4	62	$1\frac{11}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	15	15	$19\frac{7}{8}$	$19\frac{7}{8}$	$19\frac{7}{8}$	$19\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{32}$	$\frac{3}{4}$
5	59	$1\frac{5}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	19	19	19	19	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{9}{64}$	$1\frac{1}{8}$
6	50	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	12	12	$18\frac{1}{8}$	$18\frac{1}{8}$	$18\frac{1}{8}$	$18\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{1}{8}$	$1\frac{1}{2}$
7	41	$1\frac{7}{16}$	$\frac{11}{32}$	$\frac{11}{32}$	10	10	17	$16\frac{7}{8}$	17	$16\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{64}$	2
8	33	$1\frac{3}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	8	8	15	$15\frac{1}{16}$	15	$15\frac{1}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{32}$	3

Cylinder 15 inches diameter; stroke 24 inches; steam-ports 14x1⅛ inches; exhaust-ports 14x2¾ inches; throw of eccentric 4 inches; lead 1-16 inch, in full stroke; stud on saddle ½ inch back of centre line of link, towards axle; outside lap ¾ inch on each end of valve, face being ¾ inch longer than the extreme distance between the outside edges of steam-port, inside having no lap; width of cavity, or throat of valve, the total distance between the inner edges of steam-ports, rocker-shaft being used.

Table No. 3.—Taken from the same engine as that of Table No. 2, with the lead increased to 3/8 inch, in full-stroke; we therefore learn from Table No. 3, increasing the lead lessens the period of expansion, and hastens compression, and increases counter pressure by early lead. By referring to this table, when cutting off at half-stroke, we learn by the table lead has increased over one hundred per cent above that shown in Table No. 2; and, when cutting off at one-third of the stroke, we also find one hundred per cent of increase of lead, therefore showing that lead is not to be allowed, as it creates a terrible counter-pressure by the premature or too early admission of steam, which rapidly increases with lead, as is shown by the tables.

Table No. 4.—Diameter of cylinder, 16 inches; stroke, 24 inches; throw of eccentric, 4½ inches; lap of valve, 5/8 inch on each end, length of valve-face being 1¼ inches longer than the total distance between the outside edges of steam-ports, inside having no lap; the width of throat, or cavity of valve, being the same length as the distance between the inside edges of steam-ports. This table shows the effect of 5-16 inch lead, in full stroke, with 5/8 inch lap. In referring back to Tables Nos. 2 and 3, we find that the distribution of steam, in Table No. 4, is a little better than Table No. 3, and not so good as Table No. 2, as the period of expansion is lessened six per cent and compression hastened sixteen per cent earlier in the stroke; and premature, or early lead, takes place twenty-seven per cent earlier than is shown in Table No. 2. It is easily to be seen that lead, in all cases, creates a counter-pressure, by premature admission of steam, and lessens the period of expansion, and hastens compression; it also makes the period of

VALVE TABLE OF LINK MOTION—NO. III.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off, Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of Link	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	91	4	$1\frac{3}{4}$	$1\frac{5}{8}$	$21\frac{7}{8}$	22	$22\frac{7}{8}$	23	$22\frac{7}{8}$	23	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{8}$
2	79	$2\frac{7}{8}$	$1\frac{1}{16}$	1	19	$19\frac{1}{8}$	$21\frac{1}{2}$	$21\frac{1}{2}$	$21\frac{1}{2}$	$21\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{3}{4}$
3	71	$2\frac{1}{2}$	$\frac{7}{8}$	$\frac{27}{32}$	17	$17\frac{1}{16}$	$20\frac{1}{4}$	$20\frac{1}{4}$	$20\frac{1}{4}$	$20\frac{1}{4}$	$\frac{17}{32}$	$\frac{17}{32}$	$\frac{29}{32}$	$\frac{29}{32}$	$\frac{1}{4}$	$1\frac{1}{2}$
4	62	$2\frac{1}{4}$	$\frac{23}{32}$	$\frac{23}{32}$	15	15	19	19	19	19	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{16}$	$2\frac{1}{8}$
5	59	$2\frac{1}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$17\frac{3}{4}$	$17\frac{3}{4}$	$17\frac{3}{4}$	$17\frac{3}{4}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{5}{32}$	$2\frac{7}{8}$
6	50	2	$\frac{5}{8}$	$\frac{5}{8}$	12	12	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	$3\frac{1}{2}$
7	41	$1\frac{15}{16}$	$\frac{19}{32}$	$\frac{19}{32}$	10	10	15	15	15	15	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{7}{64}$	$4\frac{1}{2}$
8	33	$1\frac{7}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	8	8	13	13	13	13	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{52}$	6

Table of link motion, taken from an engine cylinder 15 inches diameter; stroke 24 inches; steam-ports 14x$1\frac{1}{8}$ inches; exhaust-ports 14x$2\frac{1}{4}$ inches; throw of eccentric 4 inches; lead $\frac{3}{8}$ inch, in full stroke; centre of stud on saddle $\frac{1}{8}$ inch back of centre line of link, toward axle; outside lap $\frac{3}{4}$ inch on each end of valve; face of valve being $\frac{1}{4}$ inch longer than the total distance between the outside edges of steam-ports, inside having no lap; the width of cavity, or throat of valve, the total distance between the inner edges of steam-ports, rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. IV.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	88	$4\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$21\frac{1}{8}$	$21\frac{1}{4}$	23	$22\frac{7}{8}$	23	$22\frac{7}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{4}$	0
2	79	$3\frac{11}{16}$	$1\frac{1}{4}$	$1\frac{5}{16}$	19	$19\frac{1}{8}$	$21\frac{7}{8}$	$21\frac{7}{8}$	$21\frac{7}{8}$	$21\frac{7}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{7}{16}$	$\frac{1}{4}$
3	71	$3\frac{1}{8}$	1	1	17	$17\frac{1}{8}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{3}{8}$	$\frac{5}{8}$
4	62	$2\frac{7}{8}$	$\frac{13}{16}$	$\frac{13}{16}$	15	15	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$\frac{33}{64}$	$\frac{33}{64}$	$1\frac{9}{64}$	$1\frac{9}{64}$	$\frac{9}{32}$	$1\frac{1}{8}$
5	59	$2\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$\frac{17}{32}$	$\frac{17}{32}$	$1\frac{5}{32}$	$1\frac{5}{32}$	$\frac{7}{32}$	$1\frac{1}{2}$
6	50	$2\frac{9}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	12	12	17	17	17	17	$\frac{17}{32}$	$\frac{17}{32}$	$1\frac{5}{32}$	$1\frac{5}{32}$	$\frac{5}{32}$	2
7	41	$2\frac{3}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	10	10	16	16	16	16	$\frac{17}{32}$	$\frac{17}{32}$	$1\frac{5}{32}$	$1\frac{5}{32}$	$\frac{1}{8}$	3
8	33	$2\frac{5}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	8	$8\frac{1}{8}$	$14\frac{1}{4}$	$14\frac{1}{4}$	$14\frac{1}{4}$	$14\frac{1}{4}$	$\frac{9}{16}$	$\frac{9}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{3}{32}$	4

Table of Link Motion, cylinder 16 inches diameter: stroke 24 inches; steam-ports 14 x 1¼ inches; exhaust 14 x 2½ inches; throw of eccentric 4½ inches; lead 5-16 inch, in full stroke; centre of stud on saddle 3-32 inch back of centre line of link, toward axle; outside lap ⅝ inch on each end of valve, face of valve being 1¼ inches longer than the extreme distance between outside edges of steam-ports, inside having no lap, the cavity or throat of valve being the same width as the distance between the inner edges of steam-ports; rocker-shaft being used.

expansion nearly the same quantity, from the fourth to the eighth notch.

TABLE NO. 5.—Diameter of cylinder, 16 inches; stroke, 24 inches; throw of eccentric, 5 inches; lap of valve, 7/8 inch on each end of valve; length of valve-face, 1¾ inches longer than the extreme distance between the outside edges of steam-port; inside lap, 1/8 inch on each end of valve; throat, or cavity of valve being ¼ inch narrower than distance between inner edges of steam-ports; lead, full-stroke, 3-16 inch, forward motion; back motion, 1/8 inch less than none, rocker-shaft is used. This valve gives a fair table, the distribution of steam is good; the perfection of the motion consists in the nicety with which its motion is timed, relatively, with the motion of the piston. The movement of the piston is absolutely dependent upon the proper timing of the admission and release or exhausting of the steam. We cannot get a perfect motion, as we have the back pressure or compression to contend with, if we give clearance to overcome the compression, that is, to widen the throat or cavity of valve, to overcome the compression; in consequence, then, the loss will be greater than the gain, as the release or exhaust will take place too early in the stroke, which will be a loss of power and a waste of fuel. It will be observed, by referring to Table No. 5, that whenever the lead is increased in the forward motion, and the lead taken off the back motion, as in this case, the increase of lead will be less, when changing the engine from full stroke to mid-gear. As will be seen, by looking over the table, we have about the same lead when working in the eighth notch, or cutting off at one-third of the stroke, as when set with 1-16 inch lead for forward and back motion.

VALVE TABLE OF LINK MOTION—NO. V.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins,		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	84	5	$1\frac{5}{8}$	$1\frac{3}{4}$	$20\frac{1}{4}$	$20\frac{1}{2}$	$23\frac{3}{8}$	$23\frac{1}{4}$	$22\frac{1}{2}$	$22\frac{5}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	0
2	79	$4\frac{3}{8}$	$1\frac{3}{16}$	$1\frac{1}{4}$	19	$19\frac{1}{4}$	$22\frac{5}{8}$	$22\frac{3}{4}$	22	22	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{11}{16}$	0
3	71	$3\frac{13}{16}$	1	$1\frac{1}{32}$	17	$17\frac{1}{8}$	22	22	21	21	$\frac{9}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{1}{2}$	$\frac{1}{16}$
4	62	$3\frac{5}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	15	15	$21\frac{1}{2}$	$21\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{3}{8}$	$\frac{1}{4}$
5	59	$3\frac{1}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$20\frac{1}{2}$	$20\frac{1}{2}$	19	19	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{5}{16}$	$\frac{3}{8}$
6	50	$2\frac{7}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	12	12	$19\frac{3}{4}$	$19\frac{3}{4}$	18	18	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{3}{32}$	$\frac{9}{16}$
7	41	$2\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	10	10	$18\frac{3}{4}$	$18\frac{3}{4}$	17	$16\frac{7}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{7}{32}$	$\frac{3}{4}$
8	33	$2\frac{5}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	8	$8\frac{1}{16}$	$17\frac{3}{4}$	$17\frac{3}{4}$	$15\frac{3}{4}$	$15\frac{5}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{5}{32}$	$1\frac{1}{8}$

Table of Link Motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 15 x 1¼ inches; exhaust ports 15 x 2¾ inches; throw of eccentric 5 inches; lead 3-16 inch, in full stroke, forward motion; back motion blind having ⅛ inch less than no lead in full stroke; centre of saddle stud ½ inch back of centre line of link, toward axle; outside lap ⅞ inch on each end of valve, face of valve being 1¾ inches longer than the distance between outside edges of steam-ports, inside lap ⅛ in on each end of valve throat of valve being ¼ inch narrower than the distance between the inner edges of steam-ports; a rocker-shaft being used.

TABLE No. 6.—It will be observed, by referring to this table, which is the same motion, taken from the same engine as Table No. 5, except the lead, it being 1-16 inch for the forward and back motion, that there is no particular gain received by increasing the lead for the forward motion, and decreasing the lead of the back motion, as is done on engine of Table No. 5, as both tables show about the same distribution of steam, except in full-stroke notch. There is a gain in favor of engine of Table No. 5, as it shows that the release or exhaust takes place a little sooner, which is of importance at this point. When working in full-stroke this gain will be overcome by the absence of lead, when working the engine in back motion, as there will not be any lead in back motion, from the first to the third notch, until the piston has passed the center; the remaining notches will have sufficient lead.

TABLES Nos. 7 and 8.—Showing the effect of inside lap; cylinder, 16 inches; stroke, 24 inches; throw of eccentric, 5 inches; lap, 1 inch on each end of valve, face of valve being 2 inches longer than the total distance between the outside edges of steam-port; inside lap ¼ inch on each end of valve; the throat of cavity of valve being ½ inch narrower than the distance between inner edges of steam-ports.

TABLE No. 8 having no inside lap, throat of valve being the same width as distance between the inner edges of steam-ports. By referring to Tables 7 and 8, we find that both tables show nearly the same percentage of release and compression, from the beginning of the stroke, for the full-stroke notch. Table No. 7, with ¼ inch inside lap, shows, that when working in the sixth, or half-stroke notch, release takes place seven per cent later

VALVE TABLE OF LINK MOTION.—NO. VI.

Notches.	Per cent of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch
1	89	5	$1\frac{13}{16}$	$1\frac{11}{16}$	$21\frac{1}{4}$	$21\frac{3}{4}$	$23\frac{3}{8}$	$23\frac{1}{2}$	$22\frac{7}{8}$	23	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	0
2	79	$4\frac{1}{16}$	$1\frac{1}{4}$	$1\frac{3}{16}$	19	$19\frac{1}{4}$	$22\frac{3}{4}$	$22\frac{7}{8}$	22	$22\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{11}{16}$	$\frac{1}{16}$
3	71	$3\frac{1}{2}$	$\frac{7}{8}$	$\frac{7}{8}$	17	$17\frac{1}{8}$	$22\frac{1}{8}$	$22\frac{1}{4}$	21	$21\frac{1}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{1}{2}$	$\frac{1}{8}$
4	62	$3\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	15	15	$21\frac{3}{8}$	$21\frac{3}{8}$	20	20	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{3}{8}$	$\frac{1}{4}$
5	59	$2\frac{15}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$19\frac{1}{4}$	$19\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{1}{4}$	$\frac{5}{16}$
6	50	$2\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	12	12	20	20	$18\frac{3}{8}$	$18\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{3}{16}$	$\frac{7}{16}$
7	41	$2\frac{5}{8}$	$\frac{13}{32}$	$\frac{13}{32}$	10	10	19	19	$17\frac{1}{16}$	17	$\frac{17}{64}$	$\frac{17}{64}$	$1\frac{1}{64}$	$1\frac{1}{64}$	$\frac{3}{16}$	$\frac{11}{16}$
8	33	$2\frac{3}{8}$	$\frac{11}{32}$	$\frac{11}{32}$	8	8	18	18	$15\frac{7}{8}$	$15\frac{3}{4}$	$\frac{9}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{3}{16}$	$\frac{11}{16}$

Table of link motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 15x1¼ inches; exhaust-ports 15x2¼ inches; throw of eccentric 5 inches; lead 1-16 inch, in full stroke; centre of saddle stud ¼ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; face of valve being 1¾ inches longer than the extreme distance between the outside edges of steam-ports; inside lap ⅛ inch on each end; the cavity, or throat of valve being ¼ inch narrower than the distance between the inner edges of steam-ports, rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. VII.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off, Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of Link	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	83	4$\frac{15}{16}$	1$\frac{3}{8}$	1$\frac{7}{16}$	19$\frac{5}{8}$	20$\frac{1}{16}$	23$\frac{7}{16}$	23$\frac{5}{16}$	22$\frac{3}{8}$	22$\frac{3}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	0
2	79	4$\frac{9}{16}$	1$\frac{3}{8}$	1$\frac{1}{4}$	19	19$\frac{3}{16}$	23$\frac{3}{16}$	23$\frac{1}{8}$	21$\frac{7}{8}$	21$\frac{7}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	0
3	71	3$\frac{11}{16}$	1	$\frac{15}{16}$	17	17$\frac{1}{8}$	22$\frac{5}{8}$	22$\frac{5}{8}$	20$\frac{3}{4}$	20$\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{9}{16}$	$\frac{1}{16}$
4	62	3$\frac{1}{2}$	$\frac{3}{4}$	$\frac{23}{32}$	15	15	22	22	19$\frac{5}{8}$	19$\frac{5}{8}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{21}{32}$	$\frac{21}{32}$	$\frac{7}{16}$	$\frac{1}{8}$
5	59	3$\frac{5}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	13$\frac{1}{2}$	13$\frac{1}{2}$	21$\frac{1}{2}$	21$\frac{3}{8}$	18$\frac{9}{16}$	18$\frac{5}{8}$	$\frac{1}{4}$8	$\frac{1}{4}$8	18	18	$\frac{3}{8}$	$\frac{3}{16}$
6	50	3$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	12	12	20$\frac{3}{4}$	20$\frac{3}{8}$	18	17$\frac{7}{8}$	$\frac{1}{4}$8	$\frac{1}{4}$8	18	18	$\frac{5}{16}$	$\frac{5}{16}$
7	41	2$\frac{15}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	10	10	20	19$\frac{15}{16}$	16$\frac{5}{8}$	16$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{1}{4}$	$\frac{1}{2}$
8	33	2$\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	8	8	19	19	15$\frac{1}{8}$	15	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{3}{16}$	$\frac{3}{4}$

Table of link motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 15x1¼ inches; exhaust-ports 15x2½ inches; throw of eccentric 5 inches; lead 1-16 inch, in full stroke; centre of saddle stud 3-32 inch back of centre line of link, toward axle; outside lap 1 inch on each end of valve, face of valve being 2 inches longer than the distance between the outside edges of steam-port, inside lap ¼ inch on each end; the throat or cavity of valve being ½ inch narrower than the distance between the inner edges of steam-ports, rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. VIII.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off, Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of Link	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	83	$4\frac{15}{16}$	$1\frac{5}{32}$	$1\frac{7}{16}$	$19\frac{7}{8}$	$20\frac{1}{16}$	23	$22\frac{15}{16}$	23	$22\frac{15}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{15}{16}$	0
2	79	$4\frac{9}{16}$	$1\frac{3}{8}$	$1\frac{1}{4}$	19	$19\frac{3}{16}$	$22\frac{5}{8}$	$22\frac{5}{8}$	$22\frac{5}{8}$	$22\frac{5}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$\frac{3}{4}$	0
3	71	$3\frac{11}{16}$	1	$\frac{15}{16}$	17	$17\frac{1}{8}$	$21\frac{5}{8}$	$21\frac{5}{8}$	$21\frac{5}{8}$	$21\frac{5}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$\frac{9}{16}$	$\frac{1}{16}$
4	62	$3\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	15	15	$20\frac{3}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$\frac{7}{32}$	$\frac{7}{32}$	$1\frac{7}{32}$	$1\frac{7}{32}$	$\frac{7}{16}$	$\frac{1}{8}$
5	59	$3\frac{5}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$20\frac{1}{8}$	$20\frac{1}{8}$	$20\frac{1}{8}$	$20\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{16}$
6	50	$3\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	12	12	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$
7	41	$2\frac{15}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	10	10	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$
8	33	$2\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	8	8	$17\frac{1}{4}$	$17\frac{1}{4}$	$17\frac{1}{4}$	$17\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{4}$

Table of link motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 15x1¼ inches; exhaust-ports 15x2¼ inches; throw of eccentric 5 inches; lead 1-16 inch, in full stroke; centre of saddle stud 3-32 inch back of centre line of link, toward axle; outside lap 1 inch on each end of valve, face of valve being 2 inches longer than the total distance between the outside edges of steam-ports, inside having no lap, the cavity or throat of valve being the same width as the distance between inner edges of steam-ports, rocker-shaft being used.

in the stroke, and compression begins seven per cent earlier, from the beginning of the stroke, than is shown in Table No. 8, with no inside lap. Table No. 7 shows, when working in the eighth notch, or cutting off at one-third of the stroke, with ¼ inch inside lap, that release takes place eight per cent later in the stroke, and compression begins eight per cent earlier, from beginning of stroke, than is shown in Table No. 8, with no inside lap; showing that inside lap prolongs expansion, and likewise increases the period of compression, to the same extent that release is deferred.

TABLES Nos. 9 and 10.—Showing the effects produced by increasing the throw of the eccentric. Table No. 9 showing the effect of 4½ inches throw of eccentric; Table 10 showing the effect of 6¼ inches throw of eccentric. Both tables were taken from the same engine, cylinder 16 inches in diameter; stroke 22 inches; outside lap ¾ inch, on each end of valve, making the valve-face 1½ inches longer than the total distance between the outside edges of steam-ports; inside has no lap, or line-and-line, as it is termed; the throat, or cavity of valve being the same width as the distance between the inner edges of steam-ports; lead 1-16 inch in full-stroke. By referring to the tables, we find very little difference in the distribution of steam, as both tables show about the same, for the four points of distribution: admission, expansion, compression, and release, which take place about the same time in both tables. Table No. 10 shows again in favor of 6¼ inch throw of eccentric, by the increase of lead and opening of steam-ports, as Table 10 shows an average of twenty per cent more lead, for all the notches, from the third to the eighth notch, and a less wire-drawing of steam, as the opening of steam-port averages ten

VALVE TABLE OF LINK MOTION.—NO. IX.

Notches.	Per cent of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of link.	Lead commences from end of stroke.
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch	Inch.	Inch.	Inch.	Inch.	Inch.
1	91	$4\frac{1}{2}$	$1\frac{9}{16}$	$1\frac{1}{2}$	$19\frac{3}{8}$	$19\frac{5}{8}$	$21\frac{3}{8}$	$21\frac{3}{8}$	$21\frac{3}{8}$	$21\frac{3}{8}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	0
2	82	$3\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{5}{32}$	18	$18\frac{1}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	[illegible]	0
3	73	$3\frac{1}{4}$	$\frac{29}{32}$	$\frac{7}{8}$	16	$16\frac{3}{16}$	20	20	20	20	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{31}{32}$	$\frac{31}{32}$	$\frac{7}{16}$	$\frac{1}{16}$
4	63	$2\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	14	$14\frac{1}{16}$	19	19	19	19	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{3}{8}$	$\frac{3}{16}$
5	56	$2\frac{9}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$12\frac{1}{2}$	$12\frac{1}{2}$	$18\frac{3}{16}$	$18\frac{1}{4}$	$18\frac{3}{16}$	$18\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{1}{4}$	$\frac{5}{16}$
6	50	$2\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	11	11	$17\frac{3}{8}$	$17\frac{1}{2}$	$17\frac{3}{8}$	$17\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{11}{64}$	$\frac{1}{2}$
7	41	$2\frac{9}{32}$	$\frac{7}{16}$	$\frac{7}{16}$	9	9	$16\frac{1}{2}$	$16\frac{1}{4}$	$16\frac{1}{4}$	$16\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{3}{16}$	$\frac{3}{4}$
8	32	$2\frac{3}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	7	7	$14\frac{7}{8}$	$14\frac{7}{8}$	$14\frac{7}{8}$	$14\frac{7}{8}$	$\frac{17}{64}$	$\frac{17}{64}$	$1\frac{1}{64}$	$1\frac{1}{64}$	$\frac{1}{8}$	$1\frac{1}{8}$

Table of link motion, cylinder 16 inches diameter; stroke 22 inches; steam-ports 15x1⅛ inches; exhaust-ports 15x2½ inches; throw of eccentric 4½ inches; lead 1-16 inch, in full stroke; centre of stud on saddle ⅛ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; inside having no lap being line and line; the throat of valve being the same width as the distance between the inner edges of steam-ports, rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. X.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins,		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	91	$6\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{4}$	$20\frac{1}{8}$	$20\frac{1}{2}$	$21\frac{1}{2}$	$21\frac{5}{8}$	$21\frac{1}{2}$	$21\frac{5}{8}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$	0
2	82	$4\frac{5}{32}$	$1\frac{3}{8}$	$1\frac{1}{16}$	18	$18\frac{1}{4}$	$20\frac{1}{2}$	$20\frac{9}{16}$	$20\frac{1}{2}$	$20\frac{9}{16}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{31}{32}$	$\frac{31}{32}$	$\frac{15}{16}$	$\frac{1}{8}$
3	73	$3\frac{5}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	16	$16\frac{1}{16}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$\frac{9}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{13}{16}$	$\frac{1}{4}$
4	63	$2\frac{7}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	14	14	$18\frac{3}{4}$	$18\frac{3}{4}$	$18\frac{3}{4}$	$18\frac{3}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{9}{16}$	$\frac{3}{8}$
5	56	$2\frac{11}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$12\frac{1}{2}$	$12\frac{1}{2}$	$17\frac{7}{8}$	$17\frac{7}{8}$	$17\frac{7}{8}$	$17\frac{7}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{1}{2}$	$\frac{5}{8}$
6	50	$2\frac{1}{2}$	$\frac{17}{32}$	$\frac{17}{32}$	11	$10\frac{7}{8}$	$17\frac{1}{16}$	$17\frac{1}{16}$	$17\frac{1}{16}$	$17\frac{1}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{7}{16}$	$\frac{7}{8}$
7	41	$2\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	9	$8\frac{15}{16}$	$16\frac{1}{8}$	$16\frac{1}{8}$	$16\frac{1}{8}$	$16\frac{1}{8}$	$\frac{21}{64}$	$\frac{21}{64}$	$1\frac{5}{64}$	$1\frac{5}{64}$	$\frac{13}{32}$	$1\frac{1}{8}$
8	32	$2\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	7	7	$14\frac{5}{8}$	$14\frac{5}{8}$	$14\frac{5}{8}$	$14\frac{5}{8}$	$\frac{11}{32}$	$\frac{11}{32}$	$1\frac{3}{32}$	$1\frac{3}{32}$	$\frac{3}{8}$	$1\frac{1}{2}$

Table of Link Motion, cylinder 16 inches diameter; stroke 22 inches; steam-ports 15 x 1¼ inches; exhaust ports, 15 x 2¾ inches; throw of eccentric 6¼ inches; lead 1-16 inch, in full stroke; centre of stud on saddle ⅜ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve, face of valve being 1½ inches longer than the extreme distance between outside edges of steam-ports, inside having no lap, the cavity or throat of valve being the same width as the distance between the inner edges of steam-ports; a rocker-shaft being used.

per cent more opening, from the first to the sixth notch, than is shown in Table No. 9. The seventh and eighth notches show the same for both tables. We also find a loss of power, by counter-pressure, produced by the increasing of fifty per cent of premature or too early lead; consequently, the counter-pressure will give greater resistance than will be gained by the increasing of opening of steam-port. We also find, by increasing the throw of the eccentric to 6¼ inches, that we have increased the slip of link about sixty per cent above that produced by the 4½ inch throw of eccentric, as will be seen by referring to the tables. We find, by increasing the throw of eccentric, it also changes the location of the centre of stud on saddle, causing it to move horizontally toward the axle, which causes the increase of slip of link, the location of centre of stud on saddle, for the 4½ inch throw of eccentric, being 3-16 inch back of centre line of link, toward axle, the 6¼ inch throw of eccentric being ⅜ inch back of the centre line of link, toward axle, and in the middle of the length of link. All saddles are generally placed in the centre of the length of link.

TABLES NOS. 11 and 12.—Showing the effect produced on the same engine, by moving the point of suspension less than ¼ inch. Cylinder 16 inches in diameter; stroke 22 inches; throw of eccentrics 4½ inches; lead ⅛ inch in full-stroke; outside lap ⅝ inch on each end of valve, face of valve being 1¼ inches longer than the extreme distance between outside edges of steam-ports, inside having no lap; the cavity or throat of valve being the same width as the distance between the inner edges of steam-ports, rock-shaft being used. Referring to Table No. 11, the point of suspension, or the locating the centre of stud on saddle 3-32 of an inch back of centre line of

VALVE TABLE OF LINK MOTION—NO. XI.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	90	$4\frac{1}{2}$	$1\frac{11}{16}$	$1\frac{9}{16}$	$19\frac{7}{8}$	$20\frac{1}{8}$	$21\frac{3}{8}$	$21\frac{1}{2}$	$21\frac{3}{8}$	$21\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{13}{16}$	0
2	77	$3\frac{1}{8}$	1	$\frac{31}{32}$	17	$17\frac{3}{8}$	$20\frac{1}{8}$	$20\frac{1}{4}$	$20\frac{1}{8}$	$20\frac{1}{4}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{27}{32}$	$\frac{27}{32}$	$\frac{3}{8}$	$\frac{1}{8}$
3	71	$2\frac{11}{16}$	$\frac{23}{32}$	$\frac{11}{16}$	15	$15\frac{3}{8}$	$19\frac{1}{8}$	$19\frac{3}{8}$	$19\frac{1}{8}$	$19\frac{3}{8}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{7}{8}$	$\frac{29}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
4	59	$2\frac{3}{8}$	$\frac{9}{16}$	$\frac{17}{32}$	13	$13\frac{3}{16}$	$18\frac{1}{8}$	$18\frac{1}{2}$	$18\frac{1}{8}$	$18\frac{1}{2}$	$\frac{19}{64}$	$\frac{5}{16}$	$\frac{29}{32}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{1}{2}$
5	50	$2\frac{3}{16}$	$\frac{1}{2}$	$\frac{15}{32}$	11	$11\frac{1}{8}$	17	$17\frac{1}{4}$	17	$17\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{16}$	1
6	41	$2\frac{1}{16}$	$\frac{13}{32}$	$\frac{25}{64}$	9	$9\frac{1}{8}$	16	16	16	16	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{1}{8}$	$1\frac{3}{8}$
7	33	$1\frac{15}{16}$	$\frac{3}{8}$	$\frac{11}{32}$	7	$7\frac{1}{4}$	$14\frac{3}{8}$	$14\frac{1}{4}$	$14\frac{3}{8}$	$14\frac{1}{4}$	$\frac{11}{32}$	$\frac{11}{32}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{32}$	2

Table of Link Motion, cylinder 16 inches diameter; stroke 22 inches; steam-ports 14 x 1¼ inches; exhaust ports, 14 x 2½ inches; throw of eccentric 4½ inches; lead 1-8 inch, in full stroke centre of stud on saddle 3-32 inch back of centre line of link, toward axle; outside lap ⅞ inch on each end of valve, face of valve being 1¾ inches longer than the extreme distance between outside edges of steam-ports, inside having no lap, the cavity or throat of valve being the same width as the distance between the inner edges of steam-ports; a rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. XII.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port: Front Stroke	Opening of Steam Port: Back Stroke	Steam cuts off, Expansion begins: Front Stroke	Steam cuts off, Expansion begins: Back Stroke	Exhaust Opens: Front Stroke	Exhaust Opens: Back Stroke	Exhaust closes, and compression begins: Front Stroke	Exhaust closes, and compression begins: Back Stroke	Lead on Steam Port: Front Stroke	Lead on Steam Port: Back Stroke	Lead on Exhaust: Front Stroke	Lead on Exhaust: Back Stroke	Slip of Link	Lead commences from end of stroke
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	90	$4\frac{1}{2}$	$1\frac{11}{16}$	$1\frac{9}{16}$	$19\frac{3}{4}$	20	$21\frac{1}{4}$	$21\frac{3}{8}$	$21\frac{1}{4}$	$21\frac{3}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	0
2	77	$3\frac{1}{8}$	$\frac{31}{32}$	$\frac{15}{16}$	17	17	$20\frac{1}{4}$	$20\frac{3}{16}$	$20\frac{1}{4}$	$20\frac{3}{16}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{27}{32}$	$\frac{27}{32}$	$\frac{3}{8}$	$\frac{1}{8}$
3	71	$2\frac{11}{16}$	$\frac{11}{16}$	$\frac{23}{32}$	$15\frac{3}{8}$	$15\frac{1}{16}$	$19\frac{3}{8}$	$19\frac{1}{8}$	$19\frac{3}{8}$	$19\frac{1}{8}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{29}{32}$	$\frac{29}{32}$	$\frac{5}{16}$	$\frac{5}{16}$
4	59	$2\frac{3}{8}$	$\frac{17}{32}$	$\frac{9}{16}$	$13\frac{3}{16}$	13	$18\frac{3}{8}$	$18\frac{1}{8}$	$18\frac{3}{8}$	$18\frac{1}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{1}{2}$
5	50	$2\frac{3}{16}$	$\frac{15}{32}$	$\frac{1}{2}$	$11\frac{1}{8}$	11	$17\frac{5}{16}$	17	$17\frac{5}{16}$	17	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{3}{16}$	1
6	41	$2\frac{1}{16}$	$\frac{23}{64}$	$\frac{13}{32}$	$9\frac{1}{16}$	9	16	16	16	16	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{1}{8}$	$1\frac{1}{2}$
7	32	2	$\frac{11}{32}$	$\frac{3}{8}$	$7\frac{1}{4}$	7	$14\frac{1}{8}$	$14\frac{3}{8}$	$14\frac{1}{8}$	$14\frac{3}{8}$	$\frac{11}{32}$	$\frac{11}{32}$	$\frac{31}{32}$	$\frac{31}{32}$	$\frac{3}{32}$	2

Table of link motion, cylinder 16 inches diameter; stroke 22 inches; steam-ports 14x1¼ inches; exhaust-ports 14x2½ inches; throw of eccentric 4½ inches; lead ⅛ inch, in full stroke; centre of stud on saddle ⅜ inch forward of centre line of link, toward cylinders; outside lap ⅝ inch on each end of valve, face of valve being 1¼ inches longer than the extreme distance between the outside edges of steam-ports, inside having no lap, the width of cavity or throat of valve being the same distance as between inner edges of steam-ports, rocker-shaft being used.

link, toward axle, it will be observed that the value of the back stroke admission of steam is greatest while the opening of steam-port, for front stroke, is greater than the opening of steam-port, for back stroke. It will be observed, also, that exhaust and compression take place on the front stroke sooner than on the back stroke, which is the reverse of that shown in Valve Table No. 12, with point of suspension or centre of saddle-stud located ⅛ inch forward of centre line of link toward cylinder; which shows the greatest value of admission of steam is given on the front stroke, and opening of steam-port greatest on the back stroke; and the exhaust and compression take place earlier on the back stroke, *vice versa* from that shown in Table No. 11, showing clearly that the proper place for the location of the centre of stud on saddle would be, for this particular motion, about on the centre line of link. It will also be observed that both tables show about the same distribution of steam, in full-stroke; while changing from full-stroke to half-stroke, and mid-gear, the change of motion takes place, showing the quality of the link motion derived from the locating the centre of stud on saddle of link, or point of suspension, as it is termed, the point of suspension being the most important of all the working centres, in regard to equalizing the cut-off or regulating the distribution of steam.

TABLE No. 13.—Showing the effect of transferring the motion of Valve Table No. 11 to a 24-inch stroke engine; by lengthening the crank and main rod to their proper lengths; the eccentrics and eccentric-rods were not disturbed. Table No. 11 being a 22-inch stroke engine, the length of connecting-rod being 77 inches, or 3½ times the length of stroke; the length of connecting-

VALVE TABLE OF LINK MOTION.—NO. XIII.

Notches.	Per cent of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch
1	91	$4\frac{1}{2}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$21\frac{3}{4}$	$21\frac{7}{8}$	$23\frac{3}{8}$	$23\frac{1}{4}$	$23\frac{3}{8}$	$23\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	0
2	79	$3\frac{1}{4}$	$1\frac{1}{16}$	1	19	$19\frac{1}{8}$	$22\frac{1}{4}$	$22\frac{1}{4}$	$22\frac{1}{4}$	$22\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{1}{16}$
3	71	$2\frac{1}{16}$	$\frac{25}{32}$	$\frac{3}{4}$	17	17	$21\frac{1}{4}$	$21\frac{1}{4}$	$21\frac{1}{4}$	$21\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{3}{8}$	$\frac{3}{8}$
4	62	$2\frac{1}{2}$	$\frac{11}{16}$	$\frac{11}{16}$	15	15	20	20	20	20	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{5}{16}$	$\frac{5}{8}$
5	59	$2\frac{3}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$19\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{1}{4}$	$\frac{7}{8}$
6	50	$2\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	12	12	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$18\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{3}{16}$	$1\frac{1}{8}$
7	41	$2\frac{1}{8}$	$\frac{13}{32}$	$\frac{13}{32}$	10	10	17	17	17	17	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{1}{8}$	$1\frac{3}{8}$
8	33	2	$\frac{3}{8}$	$\frac{3}{8}$	8	8	$15\frac{1}{4}$	$15\frac{1}{8}$	$15\frac{1}{4}$	$15\frac{1}{8}$	$\frac{21}{64}$	$\frac{21}{64}$	$\frac{31}{32}$	$\frac{31}{32}$	$\frac{3}{32}$	$2\frac{3}{8}$

Table of link motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 14x1¼ inches; exhaust-ports 14x2¼ inches; throw of eccentric 4½ inches; lead ⅛ inch full stroke, centre of stud on saddle 3-32 back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; face of valve being 1¼ inches longer than the extreme distance between outer edges of steam ports; inside having no lap the cavity or throat of valve being the width of the distance between the inner edges of steam-ports, rocker-shafts being used.

rod of Valve Table No. 13, 84 inches, being the proper length for a 24-inch stroke engine, being 3½ times the length of stroke. It will be observed, by referring to Table No. 13, that the location of centre of saddle stud 3-32 of an inch back of centre-line of link, towards axle, is the proper place for this motion, as the table shows that an equal distribution of steam takes place for admission, expansion, release and compression for the front and back stroke, also an equal opening of steam-port. We also learn, from Valve Tables Nos. 11 and 13, the distribution derived from the link, if affected slightly by the length of connecting-rod and throw of crank; as we find, by lengthening the crank 2 inches, and connecting rod 7 inches, we have gained an increase for the front stroke, and less admission of steam for the back stroke, than that shown in Table No. 11, with a shorter connecting-rod and crank; the eccentrics required the same position on the axle for both engines, also the same length of eccentric-rods precisely; therefore, the term link motion, so far as it involves the relation of the valve motion to that of the connecting-rod and crank, includes the proportion of the piston motion.

TABLES NOS. 14 and 15.—Taken from the same engine, showing the effect produced by increasing the horizontal distance between the centre of knuckle-joints and centre line of link, toward axle, to 4 inches, being 1½ inches more than is generally given; cylinder 16 inches in diameter; stroke 24 inches; throw of eccentric 5½ inches; lead ⅛ inch, in full stroke; centre of stud on saddle, of Table No. 14, 1 inch back of centre line of link; No. 15, ¼ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve, face of valve being 1½ inches longer than the total distance be-

VALVE TABLE OF LINK MOTION.—NO. XIV.

Notches.	Per cent of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch,
1	90	5 5/16	1 7/8	1 3/4	21 1/2	21 5/8	23 1/2	23 3/8	23 1/4	23 1/8	1/8	1/8	13/16	13/16	1 5/8	0
2	79	3 3/4	1 1/8	1 3/32	19	19	22 1/2	22 3/8	22	21 7/8	1/4	1/4	15/16	15/16	1 1/8	1/8
3	71	3 5/16	7/8	27/32	17	17	21 3/4	21 5/8	21	20 7/8	17/32	17/32	31/32	31/32	15/16	3/8
4	62	2 7/8	11/16	11/16	15	15	20 3/4	20 1/2	20	19 3/4	5/16	5/16	1	1	13/16	5/8
5	59	2 3/4	5/8	5/8	13 1/2	13 1/2	20 1/8	19 7/8	19 3/8	18 7/8	5/16	5/16	1	1	25/32	1
6	50	2 5/8	1/2	1/2	12	12	19 3/8	19 1/8	18 1/2	18	5/16	5/16	1	1	3/4	1 1/2
7	41	2 1/2	7/16	7/16	10	9 7/8	18	17 3/4	17	16 5/8	21/64	21/64	1 1/64	1 1/64	23/32	2
8	33	2 3/8	3/8	3/8	8	7 7/8	17	16 3/4	15 1/2	15 1/4	11/32	11/32	1 1/32	1 1/32	11/16	2 5/8

Table of link motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 15x1¼ inches; exhaust-ports 15x2½ inches; throw of eccentric 5½ inches; lead ⅛ inch full stroke, centre of stud on saddle 1 inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; face of valve being 1⅛ inches longer than the total distance between outside edges of steam ports; inside lap 1-16 inch on each end of valve; the cavity or throat of valve being ⅛ inch narrower than the distance between inner edges of steam-ports, rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. XV

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins,		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	90	$5\frac{1}{2}$	$1\frac{15}{16}$	$2\frac{3}{32}$	$21\frac{5}{8}$	$21\frac{3}{4}$	$23\frac{3}{8}$	$23\frac{3}{8}$	$23\frac{1}{4}$	$23\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{13}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$	0
2	79	$3\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	19	$19\frac{1}{16}$	$22\frac{3}{8}$	$22\frac{7}{16}$	$21\frac{7}{8}$	$21\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{11}{16}$	$\frac{1}{8}$
3	71	$3\frac{5}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	17	17	$21\frac{1}{2}$	$21\frac{1}{2}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	1	1	$\frac{1}{2}$	$\frac{3}{8}$
4	62	3	$\frac{3}{4}$	$\frac{3}{4}$	15	15	$20\frac{5}{8}$	$20\frac{5}{8}$	$19\frac{7}{8}$	$19\frac{7}{8}$	$\frac{11}{32}$	$\frac{11}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{7}{16}$	$\frac{9}{16}$
5	59	$2\frac{3}{4}$	$\frac{5}{8}$	$\frac{5}{8}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$19\frac{1}{16}$	19	$\frac{11}{32}$	$\frac{11}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{3}{8}$	$\frac{3}{4}$
6	50	$2\frac{5}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	12	12	$19\frac{1}{8}$	$19\frac{1}{8}$	18	18	$\frac{11}{32}$	$\frac{11}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{11}{32}$	1
7	41	$2\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	10	10	18	18	$16\frac{3}{4}$	$16\frac{7}{8}$	$\frac{23}{64}$	$\frac{23}{64}$	$1\frac{3}{64}$	$1\frac{3}{64}$	$\frac{5}{16}$	$1\frac{3}{8}$
8	33	$2\frac{13}{32}$	$\frac{7}{16}$	$\frac{7}{16}$	8	8	$16\frac{3}{4}$	$16\frac{5}{8}$	$15\frac{3}{8}$	$15\frac{1}{4}$	$\frac{23}{64}$	$\frac{23}{64}$	$1\frac{3}{64}$	$1\frac{3}{64}$	$\frac{9}{32}$	$1\frac{3}{4}$

Table of Link Motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 15x $1\frac{1}{4}$ inches; exhaust ports, 15 x $2\frac{1}{2}$ inches; throw of eccentric $5\frac{1}{2}$ inches; lead 1-8 inch, in full stroke; centre of stud on saddle $\frac{1}{4}$ inch back of centre line of link, toward axle; outside lap $\frac{3}{4}$ inch on each end of valve, inside lap 1-16 inch on each end of valve, throat of valve being $\frac{1}{2}$ inch narrower than the distance between inner edges of steam-ports; rocker-shaft being used.

tween the outside edges of steam-ports; inside lap 1-16 inch on each end of valve, the cavity or throat of valve being ⅛ inch narrower than the distance between the inner edges of steam-ports; rock-shaft used. By referring to Table No. 14, we learn, by increasing the horizontal distance from 2½ inches to 4 inches, between the centre of knuckle-joint and centre line of link, toward axle, that it causes considerable change in the motion, as Table No. 14 shows an average increase of 70 per cent of slip of link above that shown in Table No. 15, with knuckle-joint centres 2½ inches back of centre line of link, being 1½ inches less distance than that of Table No. 14. We also learn from Table No. 14, that we have increased lead which takes place 54 per cent earlier, on an average, from the fifth to the eighth notch, than is shown in Table No. 15, with 2½ inches distance between knuckle-joint centres and centre line of link, the location of centre of stud on saddle ¼ inch back of centre line of link, toward axle, and in centre of length of link, the valve receiving the same travel as the throw of eccentric; while that of Valve Table No. 14, with knuckle-joint centre 4 inches back of centre line of link, the valve receives 3-16 inch less travel than the throw of the eccentric; also showing an average of 25 per cent less opening of steam-port, which is caused by the centre of stud on saddle being located 1 inch back of centre line of link, toward axle. It will be observed the greater the distance the knuckle-joint centres are from the centre line of link the greater will be the distance of the locating of the centre of stud on saddle, in the same direction from the centre line of link, which will also cause a greater amount of slip of link on the block, and increase of premature or too early lead. We therefore learn,

VALVE TABLE OF LINK MOTION—NO. XVI.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off, Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of Link	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	91	$5\frac{1}{2}$	2	$1\frac{13}{16}$	$21\frac{3}{4}$	22	$23\frac{1}{2}$	$23\frac{9}{16}$	$23\frac{1}{4}$	$23\frac{5}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{13}{16}$	$\frac{13}{16}$	1	0
2	79	$3\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	19	$19\frac{1}{8}$	$22\frac{3}{8}$	$22\frac{7}{16}$	$21\frac{7}{8}$	22	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{15}{16}$	$\frac{15}{16}$	$\frac{1}{2}$	$\frac{3}{16}$
3	71	$3\frac{5}{16}$	$\frac{15}{16}$	$\frac{29}{32}$	17	17	$21\frac{1}{2}$	$21\frac{1}{2}$	$20\frac{7}{8}$	$20\frac{7}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	1	1	$\frac{3}{8}$	$\frac{5}{16}$
4	62	3	$\frac{25}{32}$	$\frac{3}{4}$	15	15	$20\frac{1}{2}$	$20\frac{1}{2}$	20	20	$\frac{11}{32}$	$\frac{11}{32}$	1	1	$\frac{5}{16}$	$\frac{3}{8}$
5	59	$2\frac{7}{8}$	$\frac{21}{32}$	$\frac{21}{32}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	19	19	$\frac{11}{32}$	$\frac{11}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{1}{4}$	$\frac{7}{8}$
6	50	$2\frac{21}{32}$	$\frac{5}{8}$	$\frac{5}{8}$	12	12	$18\frac{7}{8}$	19	18	18	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{1}{4}$	$1\frac{1}{16}$
7	41	$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	10	10	18	18	$16\frac{7}{8}$	$16\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{1}{4}$	$1\frac{3}{8}$
8	33	$2\frac{3}{8}$	$\frac{15}{32}$	$\frac{15}{32}$	8	8	$16\frac{1}{4}$	$16\frac{1}{8}$	$15\frac{1}{4}$	$15\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{7}{32}$	$1\frac{7}{8}$

Table of link motion, cylinder 16x24 inches; steam-ports 15x1¼ inches; exhaust-port 15x2½ inches; throw of eccentric 5½ inches; lead ⅛ inch, in full stroke; centre of stud on saddle ¼ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve, inside lap 1-16 inch on each end of valve; throat of valve being ⅛ inch narrower than the distance between inner edges of steam-ports, rocker-shaft used.

from Valve Tables Nos. 14 and 15, by increasing the horizontal distance 1½ inches more than the general rule, from the centre line of link, back toward axle, we meet with difficulties, in the shape of increase of slip of link, also premature lead, decrease of travel of valve, and also less opening of steam-port; while the admission, expansion, release, exhaust, and compression show no material change, both tables showing the same.

TABLE No. 16.—Shows the effect of changing the location of lifting-shaft, by removing it from above the centre of axle and placing it on the same vertical line of engine, below centre of axle. It will be understood that Tables Nos. 15 and 16 were taken from the same engine, no other alteration being made whatever, except the changing of position of lifting-shaft, which was 12½ inches above centre line of axle, it being changed to 15½ inches below centre line of axle, that being the proper location when placed below the centre line of axle, the cylinder being elevated 7-32 inch to the foot. By referring to the tables, we learn that there is no particular gain produced by the changing of the location of lifting-shaft in the distribution of steam, as admission, expansion, compression and release take place at the same time in both tables.

TABLE No. 17.—Shows a slight gain in the opening of steam-ports, for the first and second notches, that being of no importance, as no gain would be derived from the increase of opening for these two notches, the full-stroke notches having sufficient opening to supply the demand for the cylinder; the notches at and approaching mid-gear, are where an increase of opening would be of importance, as the steam becomes wire-drawn by the small opening of steam-port, which cannot be avoided when using the link as a cut-off.

VALVE TABLE OF LINK MOTION.—NO. XVII.

Notches.	Per cent of admission.	Travel of valve.	Steam cuts off. Expansion begins. Front Stroke	Steam cuts off. Expansion begins. Back Stroke	Opening of Steam Port Front Stroke	Opening of Steam Port Back Stroke	Exhaust Opens. Front Stroke	Exhaust Opens. Back Stroke	Exhaust closes, and compression begins. Front Stroke	Exhaust closes, and compression begins. Back Stroke	Lead on Steam Port Front Stroke	Lead on Steam Port Back Stroke	Lead on Exhaust. Front Stroke	Lead on Exhaust. Back Stroke	Slip of link.	Lead commences from end of stroke
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch,
1	90	5	$21\frac{1}{2}$	$21\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$23\frac{1}{4}$	$23\frac{1}{2}$	$23\frac{1}{16}$	$23\frac{3}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	0
2	79	$3\frac{7}{8}$	19	$19\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$22\frac{7}{8}$	23	$22\frac{3}{16}$	$22\frac{1}{2}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{21}{32}$	$\frac{21}{32}$	$\frac{1}{2}$	$\frac{1}{16}$
3	71	$3\frac{1}{8}$	17	$17\frac{1}{8}$	$\frac{7}{8}$	$\frac{13}{16}$	22	$22\frac{1}{16}$	$20\frac{1}{4}$	$20\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{3}{8}$	$\frac{1}{8}$
4	62	$2\frac{7}{8}$	15	15	$\frac{11}{16}$	$\frac{11}{16}$	$21\frac{1}{4}$	$21\frac{1}{4}$	$19\frac{5}{8}$	$19\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{1}{4}$
5	59	$2\frac{5}{8}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$\frac{9}{16}$	$\frac{9}{16}$	$20\frac{3}{4}$	$20\frac{3}{4}$	$18\frac{3}{4}$	$18\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{3}{8}$
6	50	$2\frac{7}{16}$	12	12	$\frac{1}{2}$	$\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$17\frac{7}{8}$	$17\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{16}$	$\frac{5}{8}$
7	41	$2\frac{3}{8}$	10	10	$\frac{7}{16}$	$\frac{7}{16}$	19	19	$16\frac{7}{8}$	$16\frac{3}{8}$	$\frac{17}{64}$	$\frac{17}{64}$	$\frac{57}{64}$	$\frac{57}{64}$	$\frac{9}{64}$	$\frac{7}{8}$
8	33	$2\frac{1}{4}$	8	$7\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	18	$17\frac{7}{8}$	$15\frac{3}{8}$	$15\frac{1}{8}$	$\frac{9}{32}$	$\frac{9}{32}$	$\frac{29}{32}$	$\frac{29}{32}$	$\frac{1}{8}$	$1\frac{1}{4}$

Table of link motion, cylinder 16 inches diameter; stroke 24 inches; steam-ports 14x1¼ inches; exhaust-ports 14x2½ inches; throw of eccentric 5 inches; lead 1-16 inch full stroke, centre of stud on saddle ½ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; face of valve being 1½ inches longer than the extreme distance between outside edges of steam ports; inside lap ⅛ inch on each end of valve; the cavity or throat of valve being ¾ inch narrower than the distance between inner edges of steam-ports, rocker-shaft being used.

TABLES NOS. 8 and 18.—Showing the effect of lap, both engines having the same motion, except the outside lap. Table No. 18, cylinder 16 inches in diameter; stroke 24 inches; throw of eccentrics 5 inches; lap ¾ inch on each end of valve, face of valve being 1½ inches longer than the total distance between the outside edges of steam-ports, inside having no lap; throat or cavity of valve being the same width as the distance between the inner edges of steam-ports.

TABLE NO. 18.—With ¾ inch outside lap, shows that steam is admitted to piston 8 per cent further, when working in full-stroke notch, than is shown in Table No. 8, with 1 inch outside lap. For all the rest of the notches we find a gain much in favor of Table No. 8, with 1 inch outside lap, above Table No. 18, with ¾ inch outside lap, as the steam is deferred to 3 per cent later period of the stroke. We also find, by referring to Table No. 8, with 1 inch outside lap, that compression takes place 8 per cent later in the stroke, on an average, for all the notches, from the fifth to the eighth notch, above that shown in Valve Table No. 18, with ¾ inch lap. We also find that premature lead is reduced to a proper quantity, by increasing the lap to 1 inch outside. By referring to Table No. 8, we find 40 per cent less premature lead than is shown in Table No. 18. By referring back to Table No. 7, with 1 inch outside lap, and ¼ inch inside lap, we have decreased the power of engine, as the table shows that, by adding inside lap, we increase compression 14 per cent, while expansion is increased only 9 per cent, and does not show as good a working table as Table No. 18, with ¾ inch outside, and no inside lap. We learn from the tables, that lap may be increased to such an extent as to work the steam about one-third, or a

VALVE TABLE OF LINK MOTION—NO. XVIII.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off, Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke.
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	90	$4\frac{15}{16}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$21\frac{1}{2}$	$21\frac{3}{4}$	$23\frac{1}{16}$	$23\frac{5}{16}$	$23\frac{1}{16}$	$23\frac{5}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	$\frac{11}{16}$	0
2	79	$3\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	19	$19\frac{1}{4}$	$22\frac{1}{2}$	$22\frac{9}{16}$	$22\frac{1}{2}$	$22\frac{9}{16}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{29}{32}$	$\frac{29}{32}$	$\frac{1}{2}$	$\frac{1}{16}$
3	71	$3\frac{1}{8}$	$\frac{7}{8}$	$\frac{13}{16}$	17	$17\frac{1}{8}$	$21\frac{1}{2}$	$21\frac{1}{2}$	$21\frac{1}{2}$	$21\frac{1}{2}$	$\frac{7}{32}$	$\frac{7}{32}$	$\frac{31}{32}$	$\frac{31}{32}$	$\frac{3}{8}$	$\frac{1}{8}$
4	62	$2\frac{7}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	15	15	$20\frac{1}{2}$	$20\frac{1}{2}$	$20\frac{1}{2}$	$20\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{5}{16}$	$\frac{1}{4}$
5	59	$2\frac{5}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{1}{4}$	$\frac{3}{8}$
6	50	$2\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	12	12	19	19	19	19	$\frac{1}{4}$	$\frac{1}{4}$	1	1	$\frac{3}{16}$	$\frac{5}{8}$
7	41	$2\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	10	10	18	$17\frac{7}{8}$	18	$17\frac{7}{8}$	$\frac{17}{64}$	$\frac{17}{64}$	$1\frac{1}{64}$	$1\frac{1}{64}$	$\frac{9}{64}$	$\frac{7}{8}$
8	33	$2\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	8	8	$16\frac{3}{4}$	$16\frac{5}{8}$	$16\frac{3}{4}$	$16\frac{5}{8}$	$\frac{9}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{1}{32}$	$\frac{1}{8}$	$1\frac{1}{4}$

Table of link motion, cylinder 17 inches diameter; stroke 24 inches; steam ports $16 \times 1\frac{1}{4}$ inches; exhaust-port $16 \times 2\frac{3}{4}$ inches; throw of eccentric 5 inches; lead 1-16 inch, in full stroke; centre of stud on saddle $\frac{1}{4}$ inch back of centre line of link, toward axle; outside lap $\frac{3}{4}$ inch on each end of valve; face of valve $1\frac{1}{4}$ inches longer than the extreme distance between outside edges of steam-ports; inside no lap; width of cavity or throat of valve the total distance between inner edges of steam-port; rocker-shaft used.

VALVE TABLE OF LINK MOTION—NO. XIX.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam Cuts off. Expansion begins,		Exhaust Opens.		Exhaust closes, and Compression begins		Lead on Steam Port		Lead on Exhaust.		Slip of Link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	88	4 1/2	1 5/8	1 1/2	19 3/8	19 5/8	21 3/8	21 3/8	21 1/4	21 1/4	1/16	1/16	3/4	3/4	3/4	0
2	82	3 7/8	1 1/4	1 3/16	18	18 3/8	21	21 1/8	20 1/2	20 5/8	1/8	1/8	13/16	13/16	5/8	0
3	73	3 1/4	7/8	7/8	16	16 1/4	20 1/8	20 3/8	19 5/8	19 3/4	3/16	3/16	7/8	7/8	7/16	1/8
4	63	2 11/16	5/8	5/8	14	14 1/8	19 1/8	19 1/8	18 1/2	18 1/2	7/32	7/32	29/32	29/32	5/16	1/4
5	56	2 1/2	9/16	9/16	12 1/2	12 1/2	18 3/4	18 3/4	17 3/4	17 3/4	1/4	1/4	15/16	15/16	1/4	5/16
6	50	2 3/8	1/2	1/2	11	11	18	18	17	17	1/4	1/4	15/16	15/16	3/16	3/8
7	41	2 1/4	3/8	3/8	9	9	17 1/8	17 1/8	16	16	1/4	1/4	15/16	15/16	5/32	5/8
8	32	2 1/8	11/32	11/32	7	6 7/8	15 3/4	15 3/8	14 5/8	14 5/8	17/64	17/64	61/64	61/64	1/8	1

Table of Link Motion, cylinder 16 inches diameter; stroke 22 inches; steam-ports 14 x 1¼ inches; exhaust ports, 14 x 2½ inches; throw of eccentric 4½ inches; lead 1-16 inch, in full stroke; centre of stud on saddle ½ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve, face of valve being 1½ inches longer than the total distance between the outside edges of steam-ports; inside lap 1-16 inch on each end of valve; cavity or throat of valve being ⅛ inch narrower than the distance between inner edges of steam-ports; rocker-shaft being used.

trifle over the stroke, expansively, when cutting off the steam at one-third of the stroke, leaving nearly one-third for compression. By increasing the inside lap, to work the steam by expansion, to a later period, the compression will take place earlier in the stroke, to the same amount as expansion is deferred, the compression creating a greater resistance than is gained by the increased period of expansion of steam, as the pressure of steam is reduced and compression increased. By cutting off at an earlier period than one-third of stroke the steam becomes too much wire-drawn, as the opening of steam-port will not be sufficient to fill the demand of cylinder, to accomplish much work. A valve may be made to cut off at one-tenth of the stroke, when using two valves, one as a cut-off valve, the other as a main valve, the same as the old fashioned hook motion, with independent cut-off.

We learn from the valve tables given, that the distribution of steam is not affected by changing the width of steam-ports, by cutting them out, or narrowing up the bridges between the steam and exhaust ports, if the valve be changed also so as to have the same lap and lead as before the ports were altered; as we learn from the tables that lap, lead, and travel of valve control the distribution of steam, the valve controlling the four distinct movements of steam for each revolution of the crank, admission, expansion, compression and exhaust. The outside edges of steam-ports, with outside edges of valve, regulate the admission and expansion, while the inner edges of the steam-port, with inner edges of valve, regulate the exhaust and compression, as lap, lead, and travel of valve regulate the distribution of steam, and alteration of any of these will affect the motion in a definable manner. As the period of admission varies with the variation

VALVE TABLE OF LINK MOTION.—NO. XX.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off. Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of link.	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	90	5	$1\frac{3}{4}$	$1\frac{5}{8}$	$21\frac{1}{2}$	$21\frac{3}{4}$	$23\frac{9}{16}$	$23\frac{11}{16}$	$22\frac{7}{8}$	$22\frac{3}{4}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{9}{16}$	$\frac{9}{16}$	$\frac{11}{16}$	0
2	79	$3\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	19	$19\frac{1}{4}$	$23\frac{1}{4}$	$23\frac{5}{16}$	$21\frac{3}{4}$	$21\frac{7}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{21}{32}$	$\frac{21}{32}$	$\frac{1}{2}$	$\frac{1}{16}$
3	71	$3\frac{1}{8}$	$\frac{7}{8}$	$\frac{13}{16}$	17	$17\frac{1}{8}$	$22\frac{1}{2}$	$22\frac{1}{2}$	$20\frac{1}{8}$	$20\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{11}{16}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{1}{8}$
4	62	$2\frac{7}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	15	15	22	$21\frac{7}{8}$	19	$18\frac{7}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	$\frac{1}{4}$
5	59	$2\frac{5}{8}$	$\frac{9}{16}$	$\frac{9}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$21\frac{3}{8}$	$21\frac{3}{8}$	18	$17\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{8}$
6	50	$2\frac{7}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	12	12	$20\frac{3}{4}$	$20\frac{3}{4}$	$16\frac{3}{4}$	$16\frac{3}{4}$	$\frac{9}{64}$	$\frac{9}{64}$	$\frac{49}{64}$	$\frac{49}{64}$	$\frac{3}{16}$	$\frac{5}{8}$
7	41	$2\frac{3}{8}$	$\frac{7}{16}$	$\frac{7}{16}$	10	10	20	$19\frac{3}{4}$	$15\frac{3}{4}$	$15\frac{1}{2}$	$\frac{9}{64}$	$\frac{9}{64}$	$\frac{25}{32}$	$\frac{25}{32}$	$\frac{5}{32}$	$\frac{7}{8}$
8	33	$2\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	8	8	19	$18\frac{3}{4}$	$14\frac{1}{8}$	$13\frac{7}{8}$	$\frac{9}{64}$	$\frac{9}{64}$	$\frac{25}{32}$	$\frac{25}{32}$	$\frac{1}{8}$	$1\frac{1}{4}$

Table of link motion, (cylinder 16 inches diameter; stroke 24 inches; steam-ports 15x1¼ inches; exhaust-port 15x2½ inches; throw of eccentric 5 inches; lead 1-16 inch full stroke, centre of stud on saddle ¼ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; face of valve being 1½ inches longer than the extreme distance between outside edges of steam ports; inside lap ¼ inch on each end of valve; the cavity or throat of valve being ¼ inch narrower than the distance between inner edges of steam-ports, rocker-shaft being used.

VALVE TABLE OF LINK MOTION—NO. XXI.

Notches.	Per cent. of admission.	Travel of valve.	Opening of Steam Port		Steam cuts off, Expansion begins.		Exhaust Opens.		Exhaust closes, and compression begins.		Lead on Steam Port		Lead on Exhaust.		Slip of Link	Lead commences from end of stroke
			Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke		
		Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	90	5	$2\frac{1}{16}$	$1\frac{7}{8}$	$21\frac{1}{2}$	$21\frac{5}{8}$	$23\frac{1}{4}$	$23\frac{3}{8}$	$23\frac{1}{16}$	$23\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{8}$	$1\frac{3}{16}$	$1\frac{3}{16}$	$1\frac{1}{8}$	0
2	79	4	$1\frac{5}{16}$	$1\frac{3}{32}$	$19\frac{1}{16}$	$19\frac{1}{16}$	$22\frac{1}{4}$	$22\frac{1}{4}$	$21\frac{7}{8}$	$21\frac{7}{8}$	$\frac{5}{16}$	$\frac{5}{16}$	1	1	$\frac{3}{8}$	$\frac{1}{16}$
3	71	$3\frac{7}{16}$	1	$\frac{31}{32}$	17	17	$21\frac{3}{8}$	$21\frac{3}{8}$	$20\frac{7}{8}$	$20\frac{7}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{3}{8}$	$\frac{3}{8}$
4	62	$3\frac{1}{16}$	$\frac{13}{16}$	$\frac{13}{16}$	15	15	$20\frac{1}{2}$	$20\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{1}{16}$	$1\frac{1}{16}$	$\frac{5}{16}$	$\frac{5}{8}$
5	59	$2\frac{7}{8}$	$\frac{11}{16}$	$\frac{11}{16}$	$13\frac{1}{2}$	$13\frac{1}{2}$	$19\frac{3}{4}$	$19\frac{3}{4}$	$18\frac{3}{4}$	$18\frac{3}{4}$	$\frac{13}{32}$	$\frac{13}{32}$	$1\frac{3}{32}$	$1\frac{3}{32}$	$\frac{9}{32}$	$\frac{7}{8}$
6	50	$2\frac{11}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	12	12	$18\frac{7}{8}$	$18\frac{7}{8}$	$17\frac{7}{8}$	$17\frac{7}{8}$	$\frac{13}{32}$	$\frac{13}{32}$	$1\frac{3}{32}$	$1\frac{3}{32}$	$\frac{1}{4}$	$1\frac{3}{16}$
7	41	$2\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	10	10	$17\frac{3}{4}$	$17\frac{3}{4}$	$16\frac{1}{2}$	$16\frac{1}{2}$	$\frac{13}{32}$	$\frac{13}{32}$	$1\frac{3}{32}$	$1\frac{3}{32}$	$\frac{5}{32}$	$1\frac{5}{8}$
8	33	$2\frac{7}{16}$	$\frac{7}{16}$	$\frac{7}{16}$	8	8	$16\frac{1}{8}$	$16\frac{1}{8}$	15	15	$\frac{13}{32}$	$\frac{13}{32}$	$1\frac{3}{32}$	$1\frac{3}{32}$	$\frac{1}{8}$	$2\frac{1}{4}$

Table of link motion, cylinder 18 inches diameter; stroke 24 inches; steam-ports 17x1¼ inches; exhaust-port 17x2½ inches; throw of eccentric 5 inches; lead 1-8 inch, in full stroke; centre of stud on saddle ½ inch back of centre line of link, toward axle; outside lap ¾ inch on each end of valve; face of valve 1½ inches longer than the extreme distance between outside edges of steam-ports; inside lap 1-16 inch on each end of valve; throat or cavity of valve being ½ inch narrower than the distance between inside edges of steam-ports; rocker-shaft used.

of either lap, lead, or travel of valve, so also does that of expansion, which increases as the admission decreases; and a reduction of the period of admission will be the result of an increase of lap or increase of lead, or reduction of travel of valve. Each of these elements reaches its extreme qualities, as shown by the tables, as follows: lap 1 inch on each end of valve, for fast time, inside, line-and-line; heavy trains ¾ inch on each end of valve, inside, line-and-line, lead not to exceed 1-16 inch in full stroke; when required to work engine in the back notches travel of valve reaches its maximum when traveling the distance equal to the width of both steam-ports and lap of both ends of valve, added together; to the total, add 1 inch, this will give the proper travel of valve.

Same motion answers for all engines, whether 20, 22, or 24-inch stroke, as we learn from the tables that the point of suspension would be the only point affected by the changing of crank, from a 20-inch stroke to a 24-inch. stroke engine; the eccentrics require the same position, also the same lengths of eccentric-rod, for all lengths of stroke, when using the same valve motion.

The general influence common to the link motion has been pointed out and illustrated with tables with some minuteness, sufficient to show that a correct working link motion can be obtained for all cases. There are also a sufficient number of valve tables given, with different dimensions of lap, lead, and travel of valve, so that the engineer can find a table corresponding with the motion of his engine; also a table that will correspond with any alterations that he may suggest, giving a clear idea of his suggestions, without experimenting with his engine or the use of a model.

MOVEMENT OF VALVE.

Notches.	Steam cuts off.		Opening of Steam Port		Valve stops traveling, Piston moves on.		Valve commences to move back again.		Distance Piston travels while valve has no motion		Travel of valve.
	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	Front Stroke	Back Stroke	
	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
1	$20\frac{1}{4}$	$20\frac{3}{4}$	$1\frac{13}{16}$	$1\frac{11}{16}$	$7\frac{1}{4}$	S	$9\frac{1}{2}$	$11\frac{1}{4}$	$2\frac{1}{4}$	$3\frac{1}{4}$	5
2	19	$19\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{3}{16}$	5	$5\frac{1}{4}$	$8\frac{1}{2}$	$9\frac{3}{4}$	$3\frac{1}{2}$	$4\frac{1}{2}$	$4\frac{1}{16}$
3	17	$17\frac{1}{8}$	$\frac{7}{8}$	$\frac{7}{8}$	$4\frac{1}{2}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$S\frac{1}{4}$	$2\frac{3}{4}$	$3\frac{3}{4}$	$3\frac{1}{2}$
4	15	15	$\frac{3}{4}$	$\frac{3}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$5\frac{3}{4}$	$6\frac{1}{2}$	$2\frac{3}{8}$	3	$3\frac{1}{8}$
5	$13\frac{1}{2}$	$13\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$2\frac{1}{2}$	$2\frac{5}{8}$	$4\frac{1}{2}$	$5\frac{1}{4}$	2	$2\frac{5}{8}$	$2\frac{15}{16}$
6	12	12	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{7}{8}$	2	$4\frac{1}{8}$	$4\frac{1}{4}$	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{4}$
7	10	10	$\frac{13}{32}$	$\frac{13}{32}$	$1\frac{1}{2}$	$1\frac{1}{2}$	3	$3\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$2\frac{5}{8}$
8	S	S	$\frac{11}{32}$	$\frac{11}{32}$	$\frac{3}{4}$	$\frac{3}{4}$	2	2	$1\frac{1}{4}$	$1\frac{1}{4}$	$2\frac{3}{8}$

This table shows the distance the Piston moves from the commencement of its stroke; before the Valve gives its full travel or opening of steam port, when there is no loss motion. Also, showing the distance that the Piston travels while the valve has no movement, for a short period after reaching its full travel before commencing to move back again. This table was taken from Engine Cylinder 16x24 inches; link motion; rocker-shaft used. Throw of eccentric, 5 inches; outside lap of valve, ¾ inch on each end; inside lap, 1-16 inch on each end; lead on steam port, 1-16 inch full stroke.

ANGULARITY OF THE MAIN ROD.

To one desirous of mastering the intricacies of locomotive construction and of understanding the reasons for the various designs of many other mechanisms this is a very important subject. But to pursue it to an advanced degree of comprehension requires a working knowledge of the principles of that branch of mathematics called trigonometry. Those, however, who do not possess a knowledge of the principles of trigonometry should not on this account conclude that they are unable to acquire knowledge of angularity that will be of practical value to them in their everyday contact with engines of different designs; and also that will enable them approximately to account for variations in their operations.

We shall endeavor to explain the simple meaning of the term "angularity," and to illustrate it with a few diagrams, easily understood, so that the reader will understand clearly what it is.

In Fig. 70 are shown two straight lines, *A B* and *A C*, that meet in a point *A*. The opening between these lines is what is called an angle. It will be easily understood that if the line *A B* is rotated about the point *A* in a clockwise direction, or toward the line *A C*, the opening between the two lines will be reduced; and if rotated in a counter-clockwise direction the opening will be increased. Hence we shall understand that, in the first case, the angle, or opening, between the lines will be reduced, while in the second it will be increased. From that it can be seen that the angularity, or angle, of the

line A B with reference to the line A C can vary from zero, when the two lines coincide—and, we might add, make one straight line—to any number of degrees, either plus or minus, depending on the number of complete revolutions the line A B makes about the point A in either direction.

When we speak of rotating in a clockwise direction we mean in the direction in which the hands of a clock move; and of a counter-clockwise direction, moving opposite to the direction in which the hands move.

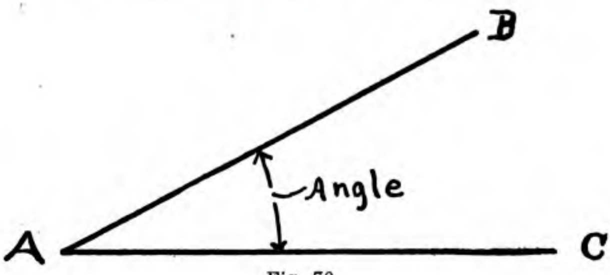


Fig. 70.

A circle is defined as an area, or plane surface, bounded by a line, called its circumference, every point of which is equally distant from a point within called the center. The distance from the center of the circle to the circumference is called the radius.

A degree of angle is the one three hundred and sixtieth part of the circumference of a circle, since all circles, no matter what the size, contain 360 degrees. Hence the amount, or extent, of the circumference comprehended between any two radii of a circle measures the angle between such radii.

These definitions make clear to us what is meant by the term "angle" spoken of in the movements of the lines

in Fig. 70, and what is meant by the term "degrees" of an angle.

In Fig. 71 is represented the cylinder, piston, crosshead, main rod, main crank and crank circle of a locomotive, with the main crank, or pin, on the forward center. If we imagine a straight line drawn through the centers of the hub, main pin, crosshead, piston and cylinder it will easily be seen that another straight line drawn through the center of the main pin, lengthwise through the main rod, through the center of the wrist pin and of the cylinder will be parallel, or will coincide, with the other straight line, and hence that there will be no angle between them.

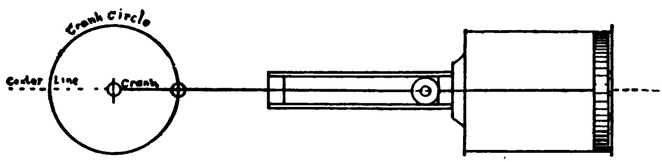


Fig. 71.

When the main pin is on the center, as shown in Fig. 71, the main rod has no angularity because its center line coincides or, as we may consider it, is parallel with the center line of the cylinder.

In Fig. 71 the crank pin is represented as having moved over a portion of its path on the crank circle in the direction of the arrow, and the piston as having moved back a portion of its stroke in the cylinder. In this figure the main rod, as may clearly be seen, stands at an angle with the center line of the cylinder; that is, considering the main rod as one straight line and the imaginary dotted line through the center of the cylinder as another, both meeting in a point at the center of the

crosshead, or the wrist pin. Hence in this position the main rod is said to have "angularity."

As the center of the crank pin travels in its circular path from the front dead center the angle of the main rod will increase from zero to a maximum, which is reached when the crank arm and the main rod stand at an angle of 90 degrees with each other, as shown in Fig. 72, and then decrease from a maximum to zero when the pin comes to the back dead center.

Enough has been said in the foregoing about angularity to give us a clear idea of the meaning of the term, and we shall now illustrate some of its effects upon the relative movements of the crank pin and the piston.

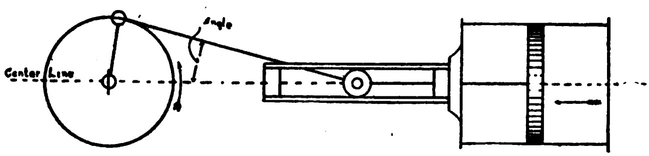


Fig. 72.

Let us look at Fig. 73. Here we have divided a circle, representing the crank pin path, into a number of equal parts, and have erected perpendiculars from a horizontal line passing through the center to each point of division. If we observe closely the spaces on the horizontal line between these perpendiculars it will be noticed that some are wider than others, although the circular spaces between the points of division on the circle are equal.

As the crank pin and crosshead are connected together by the main rod, it is clear that the distance traveled by the crosshead, which is always horizontal, will be influenced by the circular movement of the crank pin—which movement itself is a composition of a vertical and of a

horizontal movement, the resultant motion being the circle—and will be of varying distance for each degree of circular space covered by the crank pin.

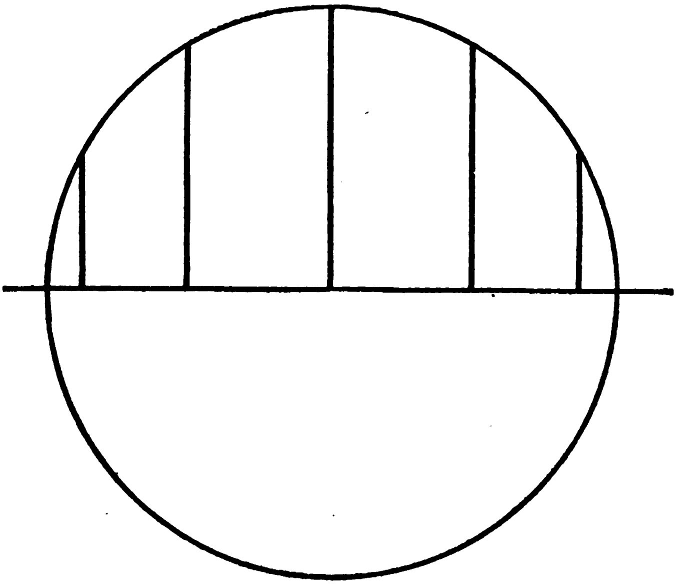


Fig. 73.

In Fig. 74 a diagram representing the path of the crank pin and the relative position of the main rod, crank pin, crosshead and piston when connected up is shown. The upper half of the path of the crank pin is divided into six equal parts of 30 degrees each.

Let us now imagine that the crank pin and main rod have moved from the front dead center to the points of division, as shown in the figure, occupying successively the positions *1-1, 2-2, 3-3,* etc. The distance traveled by

the crosshead is plainly marked, and these spaces can be seen on the diagram, without the aid of any measuring instrument, to be unequal, the shorter spaces being near the end of the guides and the longer spaces being toward the center of the guides, showing conclusively that the speed of the piston as it travels from one end of the cylinder to the other is variable, although the speed of the crank pin be uniform, and that it is greatest as the piston sweeps through the middle portion of the cylinder. This variation in piston speed is due to the angularity of the main rod. Knowledge of this simple fact is of great value to us in our study of many kinds of mechanical

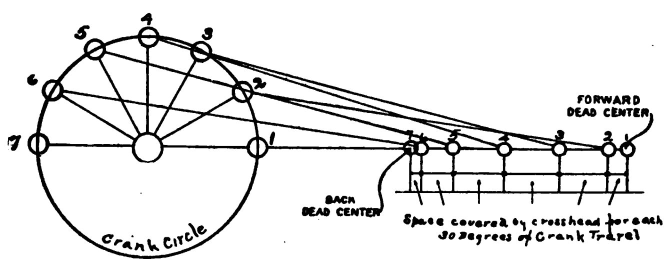


Fig. 74.

constructions; and it enables us to anticipate what the possible differences in the work and wear of locomotives, having different lengths of main rods and different lengths of stroke of piston, will be, and to compare these differences.

A little practice during spare moments on the following will serve to impress forcibly on our minds a clear understanding of the subject.

Take the engine you are firing and measure carefully the distance between the center of the wrist pin and the center of the crank pin. This distance will be the true

length of the main rod. Next measure the distance between the center of the hub of the main driving wheel and the center of the crank pin. Twice this distance will be the stroke of the engine. Now take a sheet of

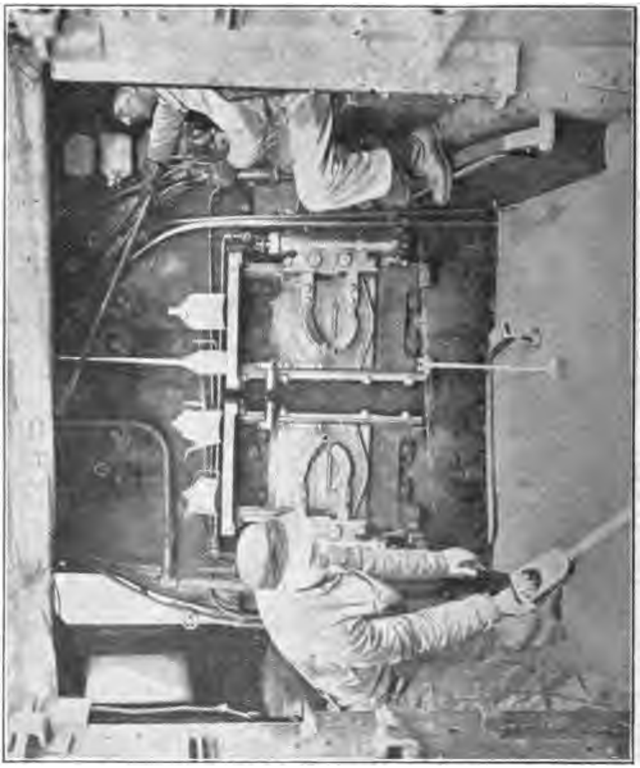


Fig. 75.

paper, the larger the better, and make a drawing to scale, like Fig. 74, which will represent the cylinder, guides, crosshead, piston and crank pin circle. Divide the upper half of the circle of the crank pin into as many equal parts as is convenient, and then determine the position of

the crosshead in the guides for each of the division points on the crank circle, as is done in Fig. 74 and note the distance that the crosshead travels for each division on the crank circle. Having done this carefully, you

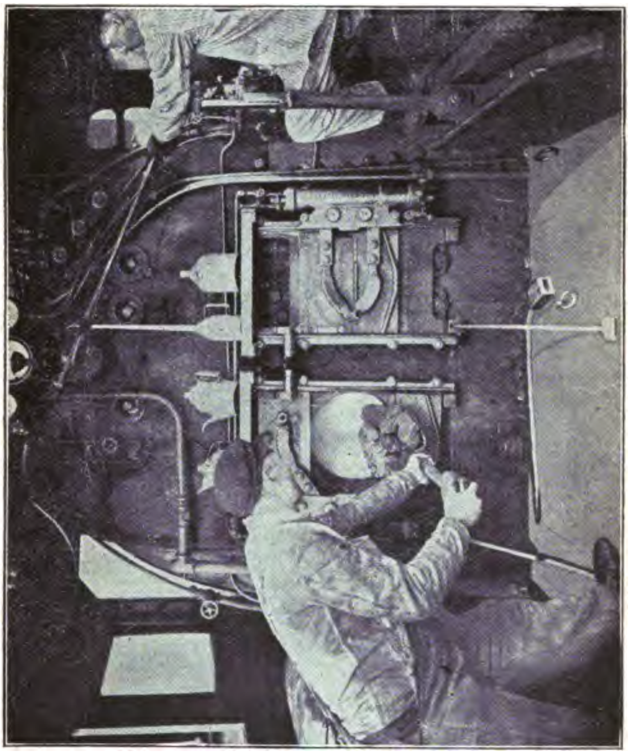
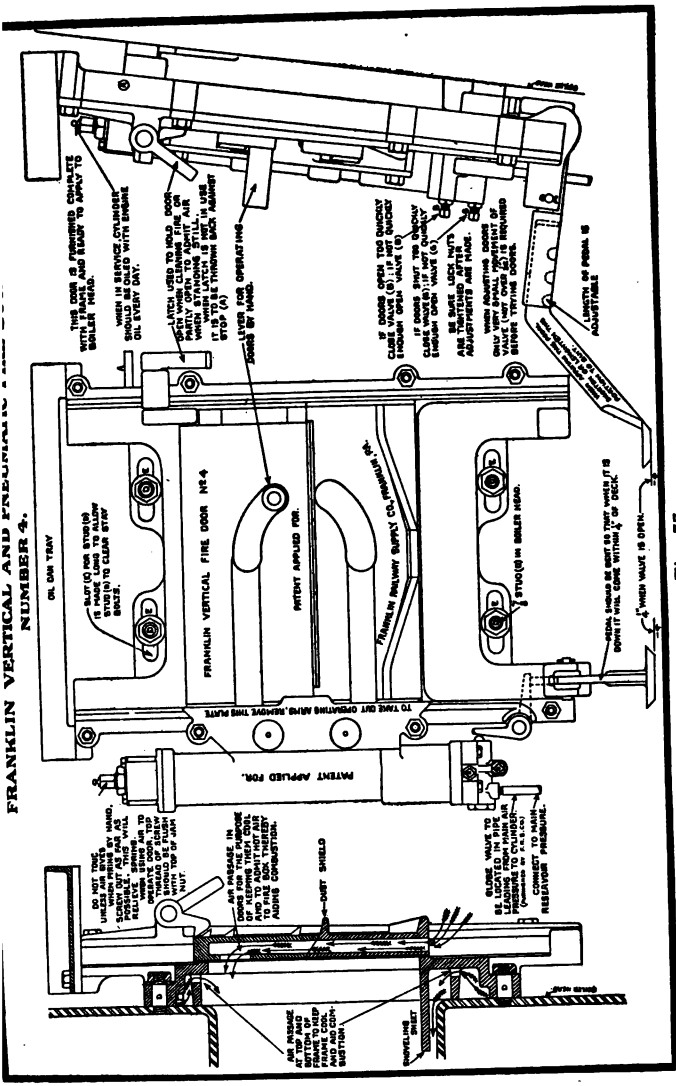


Fig. 76.

will then easily see what angularity of the main rod means for your particular engine, and what its influence is on the piston speed and on many other things bearing on the satisfactory operation of your engine.

The illustrations shown, figures 75 and 76, portray



FRANKLIN VERTICAL AND PNEUMATIC FIRE DOOR NUMBER 4.

Fig. 77.

the method of operating a Franklin pneumatic fire door. Figure 75 shows the fireman taking up a scoop of coal, the door remaining closed until he has it ready to throw in, when, as is shown in Figure 76, the door opens automatically and closes instantly. Figure 77 shows the arrangement in detail.

It is claimed that the use of this door greatly reduces the labor of the fireman by reducing the number of movements he must make, as is shown in the following comparisons:

WITHOUT THE DEVICE.

For each ton of coal consumed 585 distinct movements on the part of the fireman are required, divided as follows:

1—Filling shovel with coal.
2—Opening door.
3—Picking up shovel.
4—Throwing coal into the firebox.
5—Closing door.

WITH THE DEVICE.

The number of movements on the part of the fireman are reduced to 234, or just 40 per cent of those required with the Pneumatic Door, the remaining movements being as follows:

1—Filling the shovel with coal.
2—Putting the coal into the firebox.

Taking for the basis of calculation an engine burning ten (10) tons of coal upon a trip, with a number 4 scoop (holding on an average 17 pounds of coal) and without the door, 6,020 movements will be required, as against

,340 with the device applied, reducing the number ,680; while upon some long freight runs where twenty 20) tons of coal are consumed the movements will reach ie enormous figure of 11,700, where the door will re-eve the fireman of 7,020 of them.

The device is operated with less than 1-3000 of the ıpacity of a standard pump. It is quite simple, and has ut few parts. The slightest pressure of the foot upon ie pedal which extends upon the deck floor instantly pens the door, which is balanced, and when the foot is emoved it closes with equal rapidity. Yet, when desired, ie doors may be left open to any extent necessary when pproaching or standing at stations. When so desired ie door may be operated by hand, and since it is bal-ıced, even more conveniently than with the old style oors.

The doors being hollow prevents them from becoming o hot, it also provides for a constant flow of hot air to the fire-box while the doors are closed. This mater-ly aids combustion and to a large extent, it is claimed, duces black smoke.

The increased size and capacity of modern locomo-es has led to discussion regarding putting a second eman upon the heavy engines, but, it is said, that in es where this pneumatic door has been applied the eman has experienced no difficulty in handling the run. would therefore appear that the application of this or ilar devices may entirely solve the question and over-ne the difficulty.

REPORTING LOCOMOTIVE DEFECTS.

"No steam, right injector not working, pound on the right side, bad coal." Such reports as these are often made by the enginemen.

It is impossible to keep locomotives up to proper condition with reports of this character, because roundhouse forces are not given sufficient information to correct the difficulties. When an engine is cold in the roundhouse it is impossible for the men to discover the exact cause of the trouble and in many cases the necessary work is not done.

Many motive power officials complain of the indefiniteness of the reports of enginemen and they say it has grown worse with the increase of pooling. Undoubtedly if the men realized the importance of it they would be more explicit in their statements. On some roads such reports are not permitted, the men being required to know where the pound occurs, what the trouble with the injector is and why the engine does not steam, or if they cannot tell positively they are required to give an intelligent opinion.

It is not unreasonable to expect an engineer to know quite definitely what is wrong, and where such difficulties occur it seems fair to predict that great good would result from closer relations between the traveling engineer and the men. Would the owner of a $20,000 horse accept from his driver a statement that the animal was lame, or otherwise not right? He would certainly be justified in expecting the man to take sufficient interest

in his charge to know where he was lame or what was wrong. It can not be believed that the men who are entrusted with modern locomotives are not capable of satisfactory diagnosis.

"Poor coal is generally accepted as a reason for engine failures on most roads. There seems to be some mystic power in these two words. With proper management of the fire, "poor coal" should never lead to an engine failure. Are the locomotives designed for the coal they must use? Do the firemen receive the amount of instruction in the use of fuel that the importance of their work requires? Does the engineer feel sufficiently responsible for or interested in the work of his firemen to give him the benefit of his experience? Anything which will increase the interest of the men in their work will help these matters along wonderfully. In Europe premiums to the engineers and fireman have accomplished wonders in these directions.

PART II.

EXAMINATION QUESTIONS AND ANSWERS FOR PROMOTION

Figure 78. The Indispensable Fireman.

DEFINITIONS.

COMPRESSION. The closing of the exhaust by the exhaust edges of the valve and the steam thus confined in the cylinder being compressed by the approaching piston is the compression.

CUT-OFF. The portion of the stroke of the piston when the valve closes the steam port for the admission of steam to the cylinder.

CYLINDER CLEARANCE. The space between the piston and cylinder-head and valve-face when the piston is at the beginning of its stroke.

EXHAUST LAP. The amount of valve that extends over the inside edges of the steam ports when the valve is in the center of its seat.

EXHAUST. The release of the steam from the cylinder when the exhaust edge of the valve opens the port and permits the steam to escape to the exhaust passage.

EXPANSION. The expanding of the steam in the cylinder after the valve closes the port for admission.

HEATING SURFACE. All surfaces having water on one side and fire or heated gases on the other.

HEAT UNIT. A quantity of heat that will raise the temperature of one pound of water one degree or from 39° to 40° Fahr.

HORSE POWER. A power that will raise 33,000 pounds one foot high in one minute, or its equivalent.

INSIDE CLEARANCE. The amount the valve fails to

cover the inside edges of the steam port when the valve is in the center of its seat.

LAP. The amount of valve that extends over the outside edges of the steam ports when the valve is in the center of its seat.

LEAD. The amount of opening of the steam port when the piston is at the beginning of its stroke.

MECHANICAL EXAMINATIONS

FIRST YEAR

Giving Answers to Questions Adopted by the Traveling Engineers' Association, First Year Mechanical Examination : : : :

Question 1. What are a fireman's duties on arrival at round-house previous to going out on a locomotive?

Answer. Arrive in ample time to get ready for the trip, examine the bulletin board for new bulletins. On reaching the cab note condition of fire in firebox and the level of water in boiler. Dust out cab. Wipe off the boiler-head. Sweep off deck and clean coal out of gangway. See that oil cans, cab lamps and markers are clean and ready for use, and lighted if at night. The ash-pan clean and grates straight and see that they can be shaken and left straight. Know that engine is supplied with the necessary firing tools and sufficient coal, water, sand, oil and other supplies to meet the requirements of the trip. Display proper signals.

Q. 2. What pressure is indicated by the steam gauge? What is meant by atmospheric pressure?

A. The pressure in pounds per square inch in the inside of the boiler. Atmospheric pressure is the pressure of the weight of the air on the earth's surface, which at sea level is 14.7 pounds per square inch. This pressure increases below sea level and decreases above sea level in high altitudes, sometimes noticeable in the working of injectors on locomotives engaged in mountain service.

Q. 3. What is the source of power in a steam locomotive? What quantity of water ought to be evaporated in a locomotive boiler to the pound of coal?

A. Heat units contained in the fuel are the source of power. Heat is absorbed by the water in the boiler, generating steam which is converted into work by the locomotive. A heat unit is a quantity of heat that will

raise the temperature of one pound of water one degree. The quantity of water evaporated per pound of coal in a locomotive boiler depends upon the quality of the coal, the efficiency of the boiler and class of service. Usually six to eight pounds of water is evaporated per pound of coal in service.

Q. 4. What is steam and how is it generated?

A. Steam is water changed to a gas by the continued application of heat and is generated by raising the temperature of the water above the boiling point.

Q. 5. At what temperature does water boil?

A. Two hundred twelve (212) degrees at sea level.

Q. 6. What is the temperature of water in a boiler when the pressure is 200 pounds?

A. At 200 pounds pressure the temperature of steam is 387.7 degrees.

Q. 7. What is combustion?

A. A chemical combination resulting in heat and light, or the uniting with oxygen of any combustible matter heated to its igniting temperature.

Q. 8. What is the composition of bituminous coal?

A. Carbon, Hydrogen, Nitrogen, Oxygen, Sulphur, and ash; carbon about 80%, hydrogen about 5%, and the remaining 15% waste or non-combustible. The percentage of each element varies with different qualities of coal.

Q. 9. What is carbon? From what is oxygen obtained?

A. Carbon is a chemical element and constitutes the chief portion of all fuel. Oxygen is obtained from the atmosphere.

Q. 10. What per cent of oxygen is in the atmosphere?

A. From 20 to 23 per cent.

Q. 11. Is air necessary for combustion? Why?

A. Air is necessary and must be supplied to introduce sufficient oxygen into the firebox to maintain combustion; without oxygen fuel would not burn. (Note: Try an oil stove in a closed room for an example.)

Q. 12. How many cubic feet of air is necessary for the combustion of a pound of coal in a locomotive firebox?

A. About 200 to 250 cubic feet of air per pound of coal is required to supply oxygen to the fire for proper combustion.

Q. 13. What is the effect upon combustion if too little air is supplied through the fire? If too much air is supplied?

A. If sufficient air is not supplied the combustible gases escape unconsumed through the flues and stack which means a loss of fuel. If too much air is admitted the firebox sheets and flues are cooled and the temperature of the water and steam in the boiler is reduced; the expansion and contraction produce leaks in flues and staybolts, and fuel is wasted by the temperature of the gases being reduced below the igniting point.

Q. 14. What effect on combustion has the closing and opening of dampers?

A. Opening the dampers aids combustion by admitting air and oxygen. Closing the dampers excludes air and oxygen from the fire and retards combustion.

Q. 15. How is a draft created through the fire?

A. When the locomotive is at rest the draft is created by reason of the difference in the atmospheric pressure at the fire and the top of the smoke stack; the heated air and gases being lighter than the air, escape through the flues and stack to the atmosphere. This is known as

natural draft. When the engine is working the exhaust steam from the cylinders passes up through the stack producing a partial vacuum in the front end; air rushing in through the grates and flues to fill this vacuum creates a draft on the fire. At other times a forced draft is obtained by the use of a blower.

Q. 16. Describe a blower, its use and abuse?

A. A blower consists of a pipe extending from the dome or steam turret on the boiler-head to the smoke-box and directed upward nearly in line with the exhaust-pipe and stack, equipped with a valve in the cab within convenient reach of the fireman. When the valve is opened steam enters the pipe and escapes from the open end through the stack to the atmosphere producing a draft on the fire on the principle of induced currents. Its use is to create a draft on the fire when the engine is not working. Its abuse is to use it more than necessary when cleaning or raking fires at terminals or at times when the fire-door is open or a light fire on the grate. If used too freely under above conditions cold air is drawn into the firebox and flues which causes them to contract and leak.

Q. 17. What good and bad effect is produced by opening the fire-door when engine is being worked?

A. The good effect is that black smoke may be reduced and the opening of the pop valves prevented. The bad effect is fire-box and flues are chilled by the cold air which reduces the temperature. The flues being much lighter than the flue sheet, contraction takes place more rapidly and soon causes them to become loose in the sheet and leak. It is also a waste of fuel.

Q. 18. In what condition therefore should the fire be, in order that the best results may be obtained?

A. The fire should be built up properly for the anticipated service the engine is to perform, and allowed to burn down approaching summits of grades and shutting-off places if time will permit. Fire should be maintained at uniform thickness and free from clinkers if possible, using no more fuel than necessary to keep a uniform pressure on boiler.

Q. 19. What effect has the fire upon a scoopful of coal when it is placed in the firebox?

A. When a scoopful of coal is placed in the fire it absorbs heat and the gases are driven off or liberated which mix very quickly with the air in the firebox and if at the igniting temperature produce as near perfect combustion as is obtainable.

Q. 20. What is the effect of putting too many scoops of coal on a bright fire? Is this a waste of fuel?

A. The effect is the more coal placed on the fire at one time, the more the temperature of the firebox is reduced which brings it below the igniting temperature of the gases, and the large volume of gases liberated in this irregular manner are not mixed with the air in the firebox, but are drawn through the flues unconsumed, causing expansion and contraction of the firebox and sheets and increasing the amount of black smoke. It is a waste of fuel and causes the fire to become clinkered or dirty very quickly and leaky flues result.

Q. 21. In what condition should the fire be to consume the gases?

A. The fire should be kept burning brightly at as high and even a temperature as possible.

Q. 22. What is the temperature of the fire when in this condition?

A. From 2,000 to 2,500 degrees, as the igniting tem-

perature of the gases is about 1,800 degrees. I would aim to keep the fire as bright as possible.

Q. 23. How can the fire be maintained in this condition?

A. By putting in a small quantity of fuel at a time, firing light and often.

Q. 24. What is black smoke? Is it combustible?

A. Black smoke is a mixture of gases and carbon, the greater part of which is carbon, and *is* combustible. But in locomotive service it cannot be consumed after it is formed.

Q. 25. How can black smoke be avoided?

A. By firing light and often with an engine in good condition and properly drafted, a fair grade of coal, and the engineer and fireman working in harmony, unnecessary black smoke may be avoided.

Q. 26. Have you made an effort to practice the smokeless method of firing? What results?

A. I have tried it and on some locomotives and under certain conditions made a success. But failed on other engines and runs when conditions were adverse.

Q. 27. Can the firing be done more intelligently if the water level is observed closely? Why?

A. By watching the water level closely the fireman can anticipate the amount of water necessary for the boiler supply and fire accordingly, allow the fire to burn, and prevent coal being wasted by open pop valves, in case the water level is at its maximum height prior to closing the throttle for a station stop or descending a grade.

Q. 28. What advantage is it to the fireman to know the grades of the road and location of stations?

A. The fireman should know the road in order to fire

in an economical manner. When familiar with the road and the work of the run he can prepare the fire sufficiently in advance of the work the engine is to perform and thereby carry a more uniform pressure on the boiler, making the work of firing much easier and save coal. Without knowing the road it's all up-hill to him, and he fires in fear of a hard pull where the engine is working light, much coal will be used unnecessarily.

Q. 29. What is the purpose of a safety valve on a locomotive boiler? Why are more than one used?

A. The purpose of a safety valve on a locomotive boiler is to relieve the boiler of pressure above that which the boiler is designed to carry. On light power the second safety valve is for the purpose of relieving the boiler in case one pop valve becomes defective or inoperative. On boilers with large grate area, one pop valve will not provide sufficient opening to relieve the pressure at all times, therefore three or more valves are used.

Q. 30. What should be done to prevent waste of steam through the safety valve?

A. Prevent waste from this cause as far as possible by close attention to firing, dropping dampers and putting on heaters or injector if shut off and room for water. If working would increase boiler feed, open door on latch, or put in a scoop of coal if fire is right for it. Would use my best judgment in this to prevent waste of steam.

Q. 31. What is the estimated waste of coal for each minute the safety valve is open?

A. Fifteen pounds per minute, but with large pops and high pressure it sometimes exceeds this amount.

Q. 32. What should be the condition of the fire on arriving at a station where stop is to be made?

A. Fire should be burned to a condition that would cause no waste of steam from the pop valves, or black smoke if possible to avoid it.

Q. 33. How should you build up the fire when at stations, in order to avoid black smoke?

A. Have the coil well broken and fire as little at a time as conditions permit, using the blower, fire door and dampers to prevent black smoke.

Q. 34. What should be the condition of the fire when passing over the summit of a long grade?

A. It should be burned down the same as for a station stop.

Q. 35. If the injector is to be used after throttle is shut off, how should the fire be maintained.

A. The fire should be kept burning brightly; use blower if necessary to keep fire bright and boiler at proper temperature.

Q. 36. What would be the result of starting a heavy train with too thin a fire on the grates?

A. The coal would be lifted from the grates and holes formed in the fire, admitting cold air which would reduce the firebox temperature and cause a corresponding reduction of the boiler pressure. Avoid this by keeping fire at proper thickness on grates for the work to be done at all times.

Q. 37. Where, as a rule, should the coal be placed in the firebox?

A. Coal should be scattered as evenly as possible over the grate surface if the engine is drafted to burn the fire evenly, taking care to keep the sides and corners of the grate covered slightly heavier than the center. Would close fire-door after putting in each shovelful of coal when engine is working.

Q. 38. When and for what purpose is the use of a rake on the fire bed allowable?

A. The rake should be used whenever necessary to level the fire. Its frequent use is evidence of a lack of care and skill in placing the coil properly on the grate surface.

Q. 39. Within what limits may steam pressure be allowed to vary? Why?

A. Five pounds is a reasonable limit of variation when engine is working. At shutting off places, the variation will necessarily be greater to prevent popping. The pressure on the boiler should be kept as uniform as possible to avoid leaky flues and stay-bolts.

Q. 40. Has improper firing any tendency to cause tubes to leak? How?

A. It has. Allowing the fire to become too thin or to get holes in it, or reducing the temperature of the firebox by leaving the door open while putting in coal, placing too much coal in the firebox at one time, using the blower too strongly with door open, or without sufficient fire on the grate; doing any of these things will cause variation in firebox temperatures producing expansion and contraction of tubes and firebox sheets causing them to leak.

Q. 41. What do you consider abuse to a boiler?

A. Using blower harder than necessary; firing in an indifferent manner; leaving door open while firing when engine is working; holding door wide open to prevent popping; slipping engine from ash-pit to roundhouse after fire is banked or knocked out; putting cold water in boiler when fire and steam pressure is low; running the engine with a badly clinkered or dirty fire; slugging the firebox with more coal than can be consumed; bank-

ing the fire at one end of the firebox and leaving the other end without being covered, allowing cold air to come in contact with firebox and flues.

Q. 42. How would you take care of a boiler with leaky tubes or firebox?

A. I would maintain the fire as near a uniform temperature as possible. Keep the door closed as much as possible and use the blower as little as possible, firing evenly and with coal well broken. Would not work the injector very long at a time when engine was shut off and would keep the fire free from clinker and make proper use of dampers.

Q. 43. What are the advantages of an arch in the locomotive firebox?

A. The advantages of a brick arch in a locomotive firebox are that it retains the gases longer in the firebox, giving a longer time for combustion before they are drawn through the flues, also mixes the air with the gases better and aids combustion. It prevents, in a measure, the cold air which enters the fire-door from striking the flues before it is heated and gives a uniform temperature in the firebox.

Q. 44. Why is it very important that coal should be broken so that it will not be larger than an ordinary sized apple, before being put into the firebox?

A. It is necessary to introduce air into the firebox as well as fuel to obtain combustion. When the coal is broken to about the size of an apple it does not require as much heat to make it crumble and give off the combustible gases. It absorbs the heat more quickly, due to the larger surface exposed to the fire and permits a freer flow of air through the grates and fire to combine with the gases. Combustion is more rapid, less

clinker is formed and the fire can be carried at a more even thickness on the grates.

Q. 45. When and why should you wet the coal on the tender?

A. Would not wet it at all only to keep down the dust, unless it was very fine, then would wet it only enough to give it weight to prevent its being drawn into the flues before consumed. All the water put on the coal must be evaporated before the coal will burn, and the water generated into steam in the firebox impairs the draft of the boiler.

AIR BRAKE QUESTIONS AND ANSWERS.

Q. 1. What is an air brake?

A. It is a brake applied by compressed air.

Q. 2. How is the air compressed for use in the brake system?

A. By the air pump on the locomotive.

Q. 3. What are the essential parts of the air brake as applied to a locomotive?

A. The air pump, the main reservoir, the engineer's brake valve, the train pipe with its hose and couplings, the auxiliary reservoir, the triple valve, brake cylinder, the gauge and pump governor.

Q. 4. How many kinds of triple valves are there in use?

A. Two, the plain triple and the quick-action triple.

Q. 5. What is the main reservoir used for and where is it located?

A. The main reservoir is for storing air in advance of its need for any purpose. Its air is principally used to restore pressure to the train line; also for signal line, bell ringer, air sander, blow off cock, door-opener, water scoop, etc. The main drum is usually located on the engine, but sometimes on the tender.

Q. 6. What is the usual standard train pipe pressure?

A. Seventy (70) pounds per square inch.

Q. 7. What pressure is usually carried in the main reservoir?

A. Ninety (90) to 110 pounds.

Q. 8. Why is it important that all air brake apparatus should be kept tight and free from leaks?

A. Primarily so that its use for the purposes intended will be definite, also to avoid overtaxing the pump.

Q. 9. Where does the air come from that operates the sand blower, bell ringer, blow-off cock, air whistle signal, water scoop and other devices?

A. From the main reservoir.

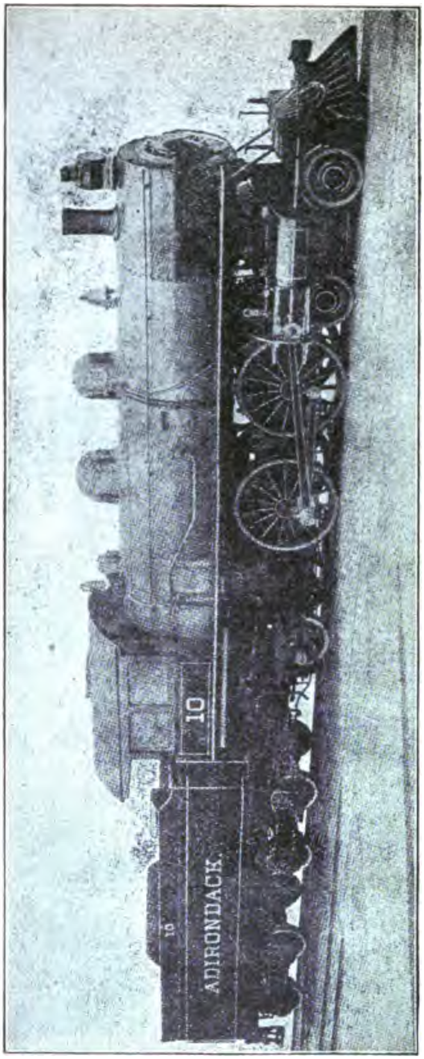


Figure 79. "Atlantic" Passenger Locomotive.

MECHANICAL EXAMINATIONS

SECOND YEAR

Giving Answers to Questions Adopted by the Traveling Engineers' Association, Second Year Mechanical Examination : : :

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Q. 1. What, in your opinion, is the best way to fire a locomotive?

A. Arrive at the locomotive on time and have everything ready for the trip, build up the fire while going to the yard for train, having fire ready and the right pressure when ready to start. Break lumps to proper size, fire light and often, close fire-door as quickly as possible after each scoopful of coal is put in firebox when engine is working. Scatter the coal over the grate surface evenly, keeping the sides and corners of grates well covered and prevent banks or holes being formed in the fire. Keep the fire hot when the injector is working with engine shut off, grates free from ashes and clinkers and the ash-pan clean. Would do my best to keep a uniform boiler pressure as near the popping point as possible without letting her pop. Watch for signals at all times when necessary and make myself useful in any manner pertaining to the duties of a fireman.

Q. 2. What is the cause of the drumming noise when engine is shut off? Can and should it be avoided? Why?

A. The drumming noise is caused by the hydrogen expelled from the coal combining in certain proportions with the oxygen present, forming oxyhydrogen gas; an explosive compound which when subjected to high temperatures, produces a series of minute explosions in the firebox. It *can* and *should* be avoided by dropping a damper and opening fire-door on latch, because it is very annoying to passengers and the public, and interferes with operators reading instruments at telegraph stations.

Q. 3. Describe the general form of a locomotive boiler.

A. The general form of a locomotive boiler is cylindrical, having a rectangular or square shaped firebox at one end and a smoke box at the other with flues extending through the cylindrical part from the flue sheet in the firebox to the flue sheet at front end of boiler, which with the firebox and all heating surface, is surrounded or exposed to contact with water.

Q. 4. How does the wide firebox type of boiler differ from the ordinary boiler, and what are the advantages?

A. It has a shallow firebox extending over the frames which permits a larger water space on sides of firebox and gives a larger grate surface per square foot of heating surface, allowing the advantage of a much slower rate of combustion. The slower the rate of combustion the more heat units are absorbed by the water and a higher efficiency is obtained from the boiler.

Q. 5. Why have two firebox doors been placed in the large type of locomotive boilers?

A. As a convenience to the fireman in placing coal where wanted on the grates, permitting one side of the firebox to have the fire at its highest temperature while coal is being placed on the grates of the other side of the firebox.

Q. 6. Describe a locomotive firebox.

A. A rectangular or square shaped box set in the end of the boiler so arranged that it may be surrounded or covered with water, and consists of a crown sheet, side sheets, door and flue sheet properly secured with flues extending from flue sheet to front end, a door through which fire may be supplied with fuel, and grates for a bottom to carry the fire and admit air for combustion.

Q. 7. To what strains is a firebox subjected?

A. Strains of expansion, contraction and compression due to the variations of temperature and the pressure of the boiler which tends to crush it.

Q. 8. How are the sheets of a firebox supported?

A. Side and end sheets are supported by stay-bolts screwed and riveted through both inside and outside sheets. Crown sheet by crown bars with ends resting on side sheets or with radical stay-bolts riveted through crown sheet and roof sheet of boiler.

Q. 9. In what manner is a crown sheet supported?

A. By crown bars and radical stays; crown bars are connected to the shell of the boiler by sling stays.

Q. 10. What are the bad features about crown bars?

A. They are heavy, expensive, take up water space and make it difficult to keep crown sheet free from mud and scale where bad water is used.

Q. 11. What are the advantages of radical stayed crown sheets?

A. They are much cheaper, allow more water over the crown sheet and permit more curve in the crown sheet, thus facilitating inspection and washing, to prevent the formation of mud and scale on the crown sheet.

Q. 12. How are the inside and outside sheets of firebox secured at the bottom?

A. They are secured by rivets extending through both sheets and the mud ring which form the bottom of the water space.

Q. 13. Describe the ash-pan and its use.

A. An iron pan-shaped box or receptacle fitted with dampers or slides under the grates, for the purpose of catching and carrying cinders and ashes which fall through the grates; dampers are operated from the cab

for the purpose of regulating the admission of air through the grates.

Q. 14. What is a wagon top boiler?

A. A boiler with the firebox end larger than the cylindrical part. Boilers without wagon tops are called straight boilers.

Q. 15. Why are boilers provided with steam domes?

A. To provide a place for throttle valve and pipes leading to steam chests, boiler attachments, whistle, air pumps, and to insure the use of dry steam as far as possible.

Q. 16. What must be the condition of a boiler in order to give the best results?

A. Should be free from leaks in firebox and flues, flues clean, properly drafted and the inside of boiler free from scale and mud to insure a good circulation of water.

Q. 17. What is meant by "circulation" in a boiler?

A. As water absorbs heat it becomes lighter and rises to the surface either as hot water or steam, the water at a lower temperature coming in contact with the heated surface of the boiler, taking the place of that evaporated, producing circulation.

Q. 18. What would be the effect if a leg of the firebox became filled with mud?

A. The mud would prevent the water from coming in contact with the firebox sheets, there would be no circulation at that part, and the mud would not absorb the heat. The effect would be that the sheet would become overheated, bulge and possibly be forced off the stay-bolts.

Q. 19. What would be the result if the firebox sheets [illegible]me overheated?

A. They would be forced off the stay-bolts by the pressure in the boiler if they were allowed to become hot enough to pull through the sheet.

Q. 20. Would it be advisable to put water on to a sheet that has become bare and red hot?

A. It would not, as the contraction taking place suddenly would be liable to injure the sheets.

Q. 21. What effect has the stoppage of a large number of flues?

A. It increases the coal consumption, decreases the heating surfaces and affects the burning of the fire, the steaming and efficiency of the engine.

Q. 22. Why are boiler checks placed so far away from the firebox?

A. That the feed water may enter the boiler as far as possible from the heating surface and become heated to a higher temperature before coming in contact with the hot sheets of the firebox.

Q. 23. What part of a locomotive boiler has the greatest pressure? Why?

A. The bottom part because steam is elastic and exerts its pressure evenly in all directions; the bottom of the boiler having to support the weight of the water in addition to the steam, has the greatest pressure.

Q. 24. What is the advantage of the extension front end?

A. It affords more room for the arrangement of draft appliances and their adjustment and a larger area of opening in the netting, thus preventing liability of throwing fire.

Q. 25. What is the object of hollow stay-bolts?

A. To admit air to the fire, aid combustion and detect

breakage of bolts, which is indicated by the appearance of steam and water at the end of fractured bolt.

Q. 26. What will cause an engine to tear holes in her fire?

A. Too sharp an exhaust, fire too thin, dirty or clinkered, working engine hard with dampers closed.

Q. 27. Name the various adjustable appliances in front end, by which the fire is regulated.

A. The exhaust-nozzle, diaphragm and petticoat pipe.

Q. 28. Explain what adjustments can be made and the effect of each adjustment on the fire.

A. Exhaust-nozzle, diaphragm, petticoat pipe and sleeve. Reducing the size of the exhaust-nozzle creates a stronger draft and increases the back pressure in the cylinders, therefore the diameter of exhaust-nozzle should be as large as possible consistent with steam making. The diaphragm regulates the burning of the fire on the grate, and the draft through the flues; raising the diaphragm causes more draft through the top flues and on the fire in the back end of the fire-box, and lowering it causes a stronger draft on the lower flues and in front end of the fire-box. The diaphragm should be adjusted to utilize the heating surface of the flues and to burn the fire evenly on the grate surface.

Then if the engine is not sharp enough on her fire, raising the lower part of the petticoat pipe above the nozzle or lowering the top part of the pipe or sleeve from the base of the stack will increase the draft on the fire. Raising the sleeve and lowering the pipe will decrease the draft on the fire. With a diamond stack and short front end the petticoat pipe is used to regulate the draft through the flues and on the fire, in the same manner as the diaphragm in the extension front

end. Lowering the sleeve increases the draft through the upper flues and raising the sleeve decreases the draft through them. Raising the pipe increases the draft through the lower flues and lowering it decreases the draft through the lower flues and on the fire in front end of fire box.

Q. 29. What does it indicate when the exhaust issues strongest from one side of the stack?

A. It indicates that the exhaust-pipe, petticoat-pipe and stack are not in line or plumb with each other and the engine will not steam properly.

Q. 30. What is the effect of leaky steam pipe joints inside of smoke box?

A. The partial vacuum formed by the exhaust steam passing through the stack will be destroyed and the engine will not steam when working, but will immediately get hot when throttle is closed. If the leak were great enough it would cause a failure for steam.

Q. 31. What causes a pull on fire-box door?

A. A dirty or clinkered fire, dampers closed, or grates without sufficient opening for the admission of air.

Q. 32. If, upon opening the fire-box, you discovered there was what is commonly called a red fire, what might be the cause?

A. A dull red fire when the engine is working is a sure indication of a leaky steam pipe in front end.

Q. 33. Is it not a waste of fuel to open fire-box door to prevent pops from opening? How can this be prevented more economically?

A. It is a waste of fuel and can be avoided by not placing coal in the fire-box so as to make this practice necessary. It can be prevented more economically by

increasing the boiler feed or using the injector that is not working as a heater to raise the temperature of the feed water in the tender, thereby saving heat units that would otherwise be wasted.

Q. 34. Describe the principle upon which the injectors work.

A. An injector works on the principle of induced currents. A current of any kind tends to induce movement in the same direction of any body with which it comes in contact. Steam enters the injector at a high temperature and with great velocity, coming in contact with the cold water which condenses the steam and absorbs the heat. A part of its velocity is imparted to the water giving it sufficient energy to force the check-valve open and enter the boiler against high pressure.

Q. 35. What is the difference between a lifting and a non-lifting injector?

A. A lifting injector is one set above the water supply. Steam entering creates a vacuum, and the atmospheric pressure on the water in the tender forces it into the injector, whence it is forced into the boiler; while a non-lifting injector has only the work of forcing the water into the boiler, being set below the water level it is always filled with water.

Q. 36. Will injector work with a leak between injector and tank? Why? Will it prime?

A. Not if the leak is above the water line and sufficiently large to destroy the vacuum, because with a lifting injector the vacuum is formed and the atmospheric pressure forces the water from the tank to the injector; when the leak is large enough to destroy this vacuum the injector will not work and will not prime.

Q. 37. If it primes good but breaks when steam is turned on wide, where would you look for the trouble?

A. Would look for obstruction in combining tubes, branch-pipe stopped up, bad leak in the water connections, check-valve stuck shut or stop valve on check closed if engine was equipped with that kind of a check.

Q. 38. If it will not prime, where would you expect to find the trouble?

A. Would ascertain if had water in tank. Main steam valve might be closed, primer valve disconnected, water valve closed or stopped up, tank valve disconnected, closed, bad leak in siphon pipe or strainer stopped up.

Q. 39. Will injector prime if checks leak bad or are stuck up? If injector throttle leaks bad?

A. On a lifting injector these leaks will prevent the necessary vacuum from being formed, and prevent the flow of water to a non-lifting injector.

Q. 40. If steam or water show at overflow pipe when injector is not working, how do you tell whether the leak is from check or injector throttle?

A. If steam shows at the overflow pipe of the injector when the injector is not working, it is the throttle that is leaking. If water and steam, it is the check-valve.

Q. 41. Will injector prime if primer valves leak? Will it prevent its working?

A. Injector will prime and it will not prevent its working.

Q. 42. Will an injector work if air cannot get into tank as fast as water is taken out?

A. Not for long, but this seldom happens and only

in cold weather where man-hole cover is frozen down air-tight.

Q. 43. Will an injector work if all the steam is not condensed by the water?

A. It will not, hence the reason injector fails to work when the water is too hot in the tender.

Q. 44. If you had to take down the tank hose, how would you stop the water from flowing out of the tank that has the siphon connection instead of the old style tank valves?

A. By opening the small cock on top of the siphon or taking out the plug provided for this purpose.

Q. 45. Is the water glass safe to run by, if the water in the glass is not moving up and down when the engine is in motion?

A. No, it is not. This is one of the best indications that the water glass is stopped up; I would always prove the water level by the use of gauge cocks.

Q. 46. Is any more water used when an engine foams than when the water is solid?

A. Yes; when the water is foaming in a boiler, on account of the water not being solid, small particles are carried with the steam into the cylinders, consequently more water is used when an engine is foaming.

Q. 47. Describe the manner in which a sight-feed lubricator operates.

A. After the lubricator is filled with oil and the steam and water valves are opened, steam enters the lubricator and is condensed. Water being heavier than oil, the oil rises to the top of the oil reservoir and enters a tube or pipe leading to the cavity around the regulating feed-valve under the sight feed glass and nipple.

At the same time the steam in the condensing chamber

condenses until the level of the water in the condensing chamber equals the height of the top of the equalizing tubes and water flows into the feed-glass and the chamber above it, until the water is level with the hole in the choke plug. Thus the pressure of steam in the equalizing tube and the pressure of steam in the main reservoir of the lubricator equalize, and the height of the water in the condensing chamber forms a pressure on the oil in the oil cavity equal to its weight in height to force the oil through the feed valve when it is open, and the buoyancy of the oil (being the lighter) causes it to rise to the surface of the water in the chamber above the sight-feed glass level with the hole in the choke plug. It is then carried by the steam that enters the equalizing tube through the choke plug to the steam chest, when the pressure on the lubricator end of the pipe is the greatest.

Q. 48. Does the draft from an open cab-window affect the working of the lubricator? Why?

A. It does. Cold air strikes the lubricator and chills the oil, which causes it to feed irregularly.

Q. 49. What else might cause irregularity of feed?

A. Choke plug with holes too large, equalizing tubes stopped up, or dirt in the lubricator.

Q. 50. If a lubricator feeds faster when throttle is closed than open, where is the trouble?

A. In the choke plugs. The action of the steam wears the hole in the choker larger and the equalization of pressure is not maintained in the chamber above the sight feed glass when the throttle is closed.

Q. 51. Will any bad results ensue from filling a lubricator full with cold oil?

A. There should be no bad results from filling a lubricator full of cold oil. Many types of lubricators are

provided with expansion chambers to prevent bulging, and if the water valve is opened, the expansion of oil would simply cause it to back up into the condensing chamber.

Q. 52. If sight-feeds get stopped up, how would you clean them out?

A. Much depends on the make of the lubricator. Usually by closing the regulating valves on the other feeds and the water valve between the condenser and the oil reservoir. Open the drain cock at the bottom of reservoir. Then if steam valve is open steam will blow through the equalizing tube, through the sight-feed glass, through the nipple into the oil reservoir and out the drain cock, carrying the obstructions with it; or remove the regulating valve and run a small wire through the nipple.

Q. 53. How would you clean out chokers?

A. If I could not blow out the obstruction when the lubricator is shut off and throttle drain cock and regulating valve open, would disconnect oil pipe from lubricator and clean out choke with a small wire or pin.

Q. 54. Which is the better practice, to close feed valves or water valves while waiting on sidings?

A. The feed valves always, as the water valve may leak, and if it does not, the supply of oil to the air pump will be cut off.

Q. 55. How can you tell if equalizing tubes become stopped up or broken?

A. If an equalizing tube were stopped up, the pressure of water above the feed glass would be reduced; and when the steam chest pressure is less than the boiler pressure or when throttle is closed, boiler pressure and the pressure of water in the condensing chamber

would force the oil through the feed valves in a stream and the lubricator would feed out the oil very quickly. If the equalizing pipe were broken off, it would lower the water level in the condensing chamber and would be detected by the sluggish manner in which the lubricator would work.

AIR BRAKE QUESTIONS AND ANSWERS.

Q. 1. Can you tell by the length of the exhaust of air from the train pipe, about how many air brake cars are coupled to the engine?

A. Yes, the longer the train line the longer the exhaust for any given reduction.

Q. 2. Does this give the number of brakes that set or the number of car lengths of train pipe coupled up?

A. Only the approximate car lengths of piping coupled up.

Q. 3. What is the difference between an application and a reduction?

A. From the time the brakes are applied until they are released, no matter how many reductions, is one application. When they are released and again set, it is another application.

Q. 4. How should a terminal test be made?

A. Beginning at the rear, the brakeman should couple all the hose and open all the angle cocks except the one at the rear, see that all the cars are cut in (except such as are marked defective), see that all the hand brakes are off, and the retainers open, with the handles pointing down. The engine should be cut in last. While the engine is charging the cars, the brakeman should pass along the train and inspect it carefully to ascertain if there are any leaks. In charging a train, the pump should be run according to the weather, in order to charge the train reasonably fast without overheating it. Where there are average leaks, an eight

inch pump should charge a train in about one-half as many minutes as there are cars; a nine-and-one-half inch pump twice as quickly. After the train is charged and the engineer is satisfied that it is reasonably free from leaks, the head brakeman (stationed at the head air brake car) should signal the rear brakeman (stationed at the rear air brake car) who should repeat the signal. After the engineer gets the signal from the rear man, he should apply fifteen to eighteen pounds in service application and place the engineer's valve on lap. The brakemen should now walk toward each other, inspecting each car, to see that it sets and holds, noting the piston travel as well. After this has been done, they should signal the engineer to release. Then the brakemen should pass each to his respective end of the air brake cars to see that all the brakes have been released, and, in winter, see that no shoes are frozen to the wheels. The head brakeman should then advise the engineer as to the number of air cars that are in good working order, and the tonnage or length of the train.

Q. 5. With two or more engines coupled to a train, which brake valve should be used to operate the brakes? Which engineer should make the test before starting?

A. The one on the leading engine. The leading engineer.

Q. 6. Give the meaning of the various signals made by the air signal whistle.

A. This should be answered in accordance with the Code of Rules of the railway by whom you are employed.

Q. 7. How many strokes per minute should an air pump be run to give good service?

A. About one complete (up and down) stroke per second, that is, 60 per minute.

Q. 8. How do you cut out a disabled brake?

A. With the old style triple valve, by turning the handle on the valve to an oblique position, midway between horizontal and vertical; with all other types of triple valves, by closing the cut-out cock in the branch pipe of the particular car or locomotive brake to be cut out.

Q. 9. How do you operate the straight air brake?

A. By placing the handle of the brake valve forward in application position, the application valve is opened admitting air from the main reservoir to the brake cylinders; by placing the handle of the brake valve back in release position, the release valve is opened allowing the air in the brake cylinders to flow to the atmosphere. Lap position is intermediate between these two extremes, and in lap position both valves are closed.

Q. 10. Explain the passage of steam from the boiler through the reducing valve to the steam heat train pipe.

A. Most of them operate bv the balancing of a spring as against the train pipe steam pressure acting upon a diaphragm. If the spring be set at any given pressure, fifty pounds for instance, steam from the locomotive boiler can pass through the valve until there is a trifle more than fifty pounds acting upon the diaphragm; this overbalances the spring and closes the supply until the train line steam pressure falls below fifty pounds.

Q. 11. If the steam heat gauge shows proper pressure, but the train pipe pressure appears to be low, what should be done?

A. See that the throttle is opened, then increase the

tension of the spring in the reducing valve. Sometimes the inner lining of old steam hose gets loose and shuts off the free passage of steam to the train, or the rear steam valve on the train may have been left open, or an end valve of some car may have become loosened from its stem.

A. Should one of the front tires break would run that wheel on to a wedge until it was about in normal position or high enough to clear the rail if the tire still remained on the wheel, remove the oil cellar and block between the bottom of the driving box and the pedestal;

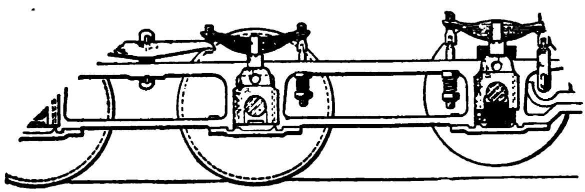

Figure 105. Blocking Broken Tire on Front Driver, Mogul Engine. Illustrating Question 82.

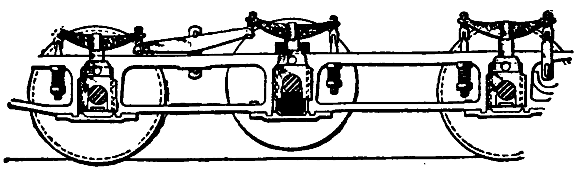

Figure 106. Blocking Broken Tire on Middle Driver, Mogul Engine. Illustrating Question 82.

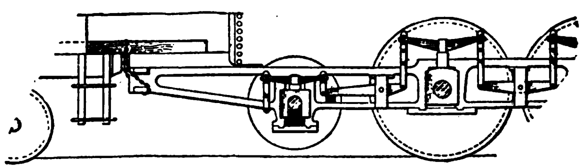

Figure 107. Blocking Broken Tire on Trailer, Atlantic Engine. Illustrating Question 82.

then cut a block and fit in place of the oil cellar for the journal to rest on. Now block between the top of the frame and spring saddle to relieve the box of the weight it carries. Cut out driver brake, and if rods were not damaged would proceed. If a main tire should break

and no other damage were done would handle in same manner; also an intermediate. If a back tire and the arrangement of the spring rigging was such that the equalizer rests on top of the back driving box it would not be possible to block between spring saddle and frame. In that case block between the back-end of spring and

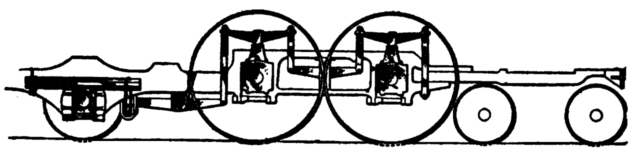

Figure 108. Blocking Broken Trailer Spring.
Illustrating Question 82.

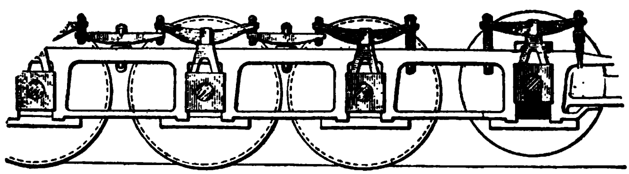

Figure 109. Blocking Broken Front Tire, Consolidation Engine.

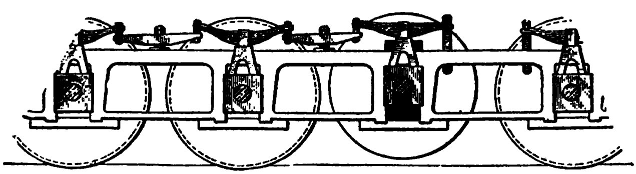

Figure 110. Blocking Broken Intermediate Tire, Consolidation Engine.
Illustrating Question 82.

lower rail of frame, so the frame would carry the load instead of the box. If this would not hold engine up, I would raise up back-end of engine and block between main driving box and frame, run slow and carefully over frogs and switches and take no chances of derailment.

For trailer tire broken I would run wheel up on wedge higher than the thickness of tire, take out the cellar, and block between the bottom of journal and box; then block between bottom of box and pedestal, and block cross equalizer in safety hanger or chain it to frame, place a tie or piece of rail from deck of engine to floor of tank and chain trailer frame to it.

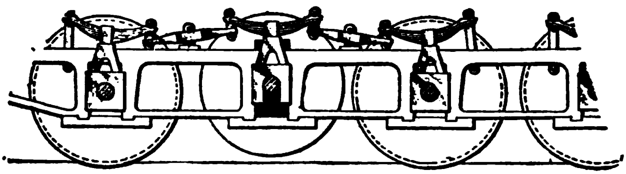

Figure 111. Blocking Broken Main Tire, Consolidation Engine.

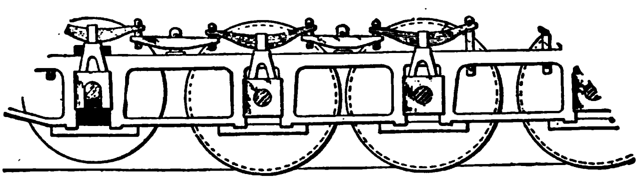

Figure 112. Blocking Broken Back Tire, Consolidation Engine. Illustrating Question 82.

When trailer wheel is blocked up in this manner would exercise care in going around curves to prevent the good trailer wheel from dropping off the rail. Wedging between engine and tender on the disabled side and close to the draw-bar would have a tendency to crowd the good wheel to the rail. I would always lubricate the blocks that the journals rest on when the cellars are removed.

Q. 83. What is a good method of raising a wheel when jacks are not available?

A. By running it up on a wedge or by cutting a block the proper length and placing it at an angle one end

against the box and the other on a tie and move the engine slowly until the block is perpendicular; this will raise the wheel or box.

Q. 84. How can it be known whether the wedges are set up too tight, and the driving box sticks, and in what manner can they be pulled down?

A. A stuck driving box can be detected very quickly by the manner in which the engine rides, and if run for a great distance the box will get hot which will further increase the trouble. They can be pulled down by means of the nut and screw used for adjustment. Would put a strain on the wedge-bolt by tightening the nut under the pedestal and run the next wheel over a coal pick or piece of iron which would jar it loose. I would not run the wheel with the stuck box over a nut or piece of iron as that would pull the wedge up and tighten the box more, if there is any slack in the head of the wedge bolt. While running the wheel next to it on a wedge or nut, it will relieve the box. Sometimes a pail of water thrown on the hot-box will contract it and assist in getting it loose. I would not run engine with stuck wedges as it causes flues to leak and loosens up all nuts, joints and pipes about the engine.

Q. 85. What are some of the various causes for pounds?

A. Loose pedestals, wedges not properly set up, rods not keyed-up, loose pistons, main-rods too long or too short, follower bolts loose, cylinders loose on frames, broken frames, brasses too large for pins and journals, flat spots in tires, and loose counterbalance blocks, cross heads, rocker boxes, etc.

Q. 86. How can a pound in driving boxes, wedges or rod brasses be located?

A. By blocking engine or quarter, opening throttle and working the reverse lever from full forward to full back gear, the lost motion in rods, wedges, boxes or other parts can be detected.

Q. 87. When should crossheads or guides be reported to be lined?

A. When they are worn so they begin to pound and there is room to insert a liner.

Q. 88. When should driving box wedges be reported to be lined?

A. When they are up as far as they can go and do not take the pound out of the box. If not properly fitted so box is allowed to rock they should be repaired when needed.

Q. 89. When should rod brasses be reported to be filed? To be lined?

A. Rod brasses should be reported to be filed when they are keyed brass to brass and still pound. And they should be reported lined or to have keys raised when driving the key will not bring the brasses together.

Q. 90. When should lost motion between engine and tender be taken up?

A. Whenever it is necessary to prevent unnecessary slack between engine and tender and to keep the tender so it will ride good.

Q. 91. Describe the principle on which an injector works?

A. The principle of the injector's action is that of induced currents; under a given pressure the velocity of escaping steam is about nine times greater than that of water and a current of any kind has a tendency to induce a movement in the same direction of any body that it passes or comes in contact with. Therefore the steam

having great velocity meeting the water in the injector induces its movement and forces the water into the boiler, gives up its heat and performs mechanical work as though it acted on a piston and moved a pump plunger along with it. When the primer or steam valve is opened on a lifting injector steam is permitted to flow out through the overflow to the atmosphere and carries some of the air from the supply pipe producing a partial vacuum there. When sufficient vacuum is formed the atmospheric pressure on the water in the tender forces the water up to the injector and out at the overflow. When the injector throttle is opened steam is permitted to pass through the injector in a much larger volume and coming in contact with the water which is flowing around the nozzle forces the water with increased velocity into the combining tube where the steam is condensed and forces the water into the boiler.

Q. 92. What is generally the cause of failure of the second injector and what should be done to obviate this failure?

A. The failure of the second injector is generally due to its not being used often enough to keep it in good working order. To obviate this would work it part of the time during each trip and know that I could rely on it in case the other injector failed.

Q. 93. What are the advantages of the combination boiler check?

A. By the use of a combination check and stop valve, the valve may be closed in the event of the check sticking up or leaking and the check removed, ground in, or repaired without letting the steam off the boiler. It also reduces failures due to stuck checks.

Q. 94. If the injector stops working out on the road, what should be done?

A. Start the other injector immediately and use it to supply boiler until the trouble with the defective injector can be ascertained. Would know sufficient water was in the tank and tank valve open and all joints in feed pipe connections tight, hose and strainer free and that the main throttle on injector was open permitting a sufficient quantity of steam to reach the injector to insure its proper working, then make sure that the combination stop and check were open or that there was a hole in the boiler for the water to be forced through. If the injector did not work, would examine tubes and ascertain if they were obstructed.

Q. 95. How can a disconnected tank valve be opened without stopping?

A. It may be opened by blowing steam back through the feed-pipe thereby blowing the valve out of its place. This depends on the construction of the tank valve and care must be exercised to prevent blowing off water hose.

Q. 96. How does the steam heat reducing-valve control the pressure?

A. The steam heat reducing-valve controls the pressure of steam to the heating system similar to the manner in which the governor on an air-pump controls the flow or pressure of steam to the air-pump, by means of a diaphragm held in position by a spring, to which is connected directly the valve that regulates the admission of steam from the boiler to the train-pipe. The tension of the spring is regulated for the desired pressure by increasing or decreasing it. When the tension of the spring is greater than the steam pressure the diaphragm and valve are forced down opening the valve and allowing the steam to flow into the train-pipe until the pressure of the steam is greater than the resistance of the

spring when the steam forces the diaphragm up and closes the valve until the pressure falls below the resistance of the spring when it is again opened by the diaphragm and spring forcing the valve off its seat. The more tension put on the spring the higher the pressure will be in the steam-pipe.

Q. 97. If steam heat gauge showed the required pressure and cars were not being heated properly, how should one proceed to locate the trouble?

A. Would open steam-valve at rear of tender and make sure there was no obstruction in the pipes from the reducing-valve to rear end of tender and that the steam-pipes were not covered with water on back of tender. Would open all valves on train-line until the rear valve was reached, blow out train-line and nearly close valve on rear end of last car, then open drip valves to let condensation out of heating coils.

Q. 98. What constitutes the abuse of an engine?

A. Working an engine harder than necessary to handle train properly and make time. Slipping engine, working water through valves and cylinders, poor pumping, careless firing that will cause flues to leak, running engine with wedges down and rods pounding, sand running on one side only, improper lubrication or generally neglecting to care for engine properly.

Q. 99. How are accidents and break-downs best prevented?

A. By being careful in handling engine and train and by proper inspection and keeping awake and attending strictly to business while out on the road.

Q. 100. What are the duties of an engineman when giving up his engine at the terminal?

A. To thoroughly inspect engine and close all feeds

on oil cups and lubricators to prevent waste of oil, and report necessary work to be done to fit engine for next trip.

Q. 101. In what manner should an engine be inspected on arrival at terminal?

A. When engine arrives at round-house or receiving track, the fire-box should be examined for leaky flues, stay or crown-bolts, and the boiler should be left reasonably full of water. Would begin at back driver when I struck the ground and note the temperature of all bearings, examine tires, wheels, eccentrics, wedge bolts, pedestal bolts, cellar bolts, springs, equalizers, and spring rigging, rocker boxes, tires and wheels, all safety appliances on front and back end of engine and tender. Would proceed around the pilot and back to the rear of tank, note that wheels, springs, brake-beams, shores and hangers were all right and see that ash-pan and screen-dampers were O. K., and look engine over very carefully until I reached the point where I commenced inspection; if any bolts or nuts were loose would tighten same and report any other defects that were necessary.

Q. 102. In reporting work on any wheel or truck on engine or tender how should they be designated?

A. Designated by number beginning with first wheel behind the pilot, as engine truck number one, or engine truck number two, right or left, using same method on tender unless the road had a different system of numbering wheels. This would not include drivers. They should be designated as R-front driver, L-main driver, R-intermediate, etc.

Q. 103. In reporting work on an engine is it sufficient to do it in a general way, such as saying an injector

won't work? Lubricator won't work? Pump won't work? Engine won't steam? Engine blows, etc.?

A. No, work should be intelligently reported to enable the machinist or foreman to locate the defect quickly and an explanation given on the work report which would insure the defect being repaired.

LUBRICATION.

Question 1. What produces friction and what is the result of excessive friction?

Answer. The movement of one body over another on the surface which it moves and the roughness of the surfaces in contact, the nature of the bodies and the pressure holding them together. The result of friction is that energy must be expended to overcome it and heat is produced.

Q. 2. What is lubrication and its objects?

A. Lubrication is the introducing of oils or other lubricants between two surfaces, which serves to keep the bearings separated and reduce the friction and resistance.

Q. 3. What examination should be made by an engineer to insure successful lubrication?

A. He should examine all oil-holes, know they are open and that all bearings show signs of being properly lubricated and that the oil reaches the bearings intended. He should know that the sponging in truck boxes and cellars is in contact with the journals and the waste on top of driving boxes has not been disturbed to allow grit or dirt to get to the bearings. If Elwin Automatic Lubricators are used in driving box cellars see that the indicators show there is sufficient grease to make the trip and that the follower in the cellar is free to force the grease through the holes in the perforated plate and that the plugs are screwed down in the rod grease-cups to insure the pins running cool, if grease is used on pins.

Q. 4. How should feeders of oil cups be adjusted?

A. They should be adjusted to feed oil positively and just enough to lubricate the bearings properly.

Q. 5. Why is it bad practice to keep engine oil close to a boiler in warm weather?

A. Because it increases the temperature of the oil and makes it much thinner, which brings it that much nearer the flashing point, and the nearer the oil is to the flashing point, the less are its lubricating qualities.

Q. 6. In what manner would you care for hot bearings when discovered on the road?

A. Would cool them off and see they were properly packed and lubricated before starting again. If it was a hot driving box would relieve it of part of its load by placing a block between spring saddle and frame if necessary.

Q. 7. What kind of oil should be used on hot bearings?

A. If the bearing was too hot to be lubricated with engine oil would use valve oil until it would run cool.

Q. 8. At completion of trip what is necessary?

A. To get the running temperature of the bearings and examine the sponging in the boxes and cellars or satisfy myself that the bearings and packing are all right.

Q. 9. How would you determine what boxes to report "examined?" Why not report all boxes examined?

A. Determine boxes to be examined by their high temperature and the condition of sponging and brass. Would not report all boxes because the box that was running cool could not be improved on and it would only mean expense and loss of oil to the company.

Q. 10. Why is it bad practice to disturb the packing on top of driving and engine truck boxes with spout of oil-can when oiling engine?

A. It allows the dirt and grit to be carried down to the bearing with the oil, increases the friction and produces a hot bearing.

Q. 11. How do you adjust grease-cups as applied to rods?

A. Loosen jamb-nut and screw down on the plug until the pressure of the plug on the grease forces it to the bearing. Just put pressure enough on the grease to meet the requirements of the service.

Q. 12. Is it usual for pins to run warmer when using grease?

A. Yes, the friction of the grease on the pins will cause them to run at a higher temperature than when oil is used. This is due to the difference in the friction of fluids and solids, the grease being a solid creates greater friction on the pins.

Q. 13. What effect does too much pressure produce?

A. It produces increased friction and a waste of grease. Therefore it is best to screw down on the grease-cups just before leaving on a trip so the stored up energy of the grease will not be expended before leaving the terminal and a supply of grease will be insured to the bearing.

Q. 14. Is it necessary to use oil with grease on crank-pins?

A. No, it is not; grease will only be softened by the use of oil or water and is not necessary, but would be a waste of lubricant.

Q. 15. Why should engine oil not be used on valves or cylinders?

A. Because it has a low flashing temperature and is not a good lubricant for hot surfaces, it burns on the

steam passages, packing rings and valve strips, causing them to gum and stick.

Q. 16. At what temperature does engine oil lose its lubricating qualities? Valve oil?

A. At its flashing point, which is about 385 degrees for engine oil and 600 to 650 degrees for valve oil.

Q. 17. How and by what means are valves, cylinders and air-pumps lubricated?

A. By the use of valve oil fed to the steam chests and cylinders by means of lubricators either hydrostatic or force-feed; occasionally graphite is used with cups provided for introducing it to the cylinders and valve surfaces.

Q. 18. How should the lubricator be filled?

A. First see that the cup is clean and free from any foreign matter likely to clog up any of the openings or lodge on the seats of the valves and prevent their closing. If the cup were dirty would blow steam through it before filling. Would fill the cup full of clean oil if had oil enough. If not would fill the balance with clear water, open water valve and steam valve wide open. When the sight-feed glasses and condenser were filled with water would open feed valves to regulate the supply of oil to the cylinders.

Q. 19. After filling lubricator what should be done?

A. Open water valve and steam valve until water filled the condensing chamber and sight-feed glasses.

Q. 20. How long before leaving terminals should the feed valves be opened?

A. Depending on the service and the profile of the road, just long enough to have the valve seats and cylinder walls lubricated.

Q. 21. How many drops should be fed per minute?

A. According to the size of the drop and the speed. Usually from 4 to 8 to the cylinders and one per minute to the air-pump will be sufficient.

Q. 22. Why is it bad practice to carry water too high in the boiler?

A. Because the steam is wet and destroys the lubrication and is less effective than dry steam; also uses more water on account of the water being carried to the cylinders with the steam instead of being evaporated in the boiler, requires more water to be supplied to the boiler at a lower temperature, and an increased fuel consumption.

Q. 23. When valves appear dry when using steam, and lubricator is working all right, what would you do to relieve conditions?

A. This is an indication of a hold-up of oil in the oil-pipe due to the steam-chest pressure being greater than the lubricator pressure. Would ease off or partly close the throttle and drop lever into full gear; this would reduce the steam chest pressure and allow the oil and water in the oil-pipes to reach the valve seats and cylinders.

AIR BRAKE QUESTIONS AND ANSWERS.

[THE AIR PUMP.]

Question 1. Explain how an air pump should be started and run on the road.

Answer. It should be started slowly to permit the condensation to be drained off. The lubricator should be started carefully and the pump worked slowly until about forty pounds has been accumulated in the main reservoir to cushion the steam and air piston of the pump. Then the throttle should be opened wider, giving a speed of about one hundred and thirty or one hundred and forty single strokes per minute. The amount of work being done really governs the speed of the pump.

Q. 2. How should the steam end be oiled?

A. By the sight-feed lubricator, with a good quality of valve oil, and at the rate of about one drop per minute. This amount will vary with the condition of pump and the work being done.

Q. 3. How should the air end of the pump be oiled, and what kind of oil used?

A. High-grade valve oil, containing good lubricating qualities and no sediment, should be used. A good swab on the piston rod will help out a great deal. Oil should be used in the air cylinder of the pump sparingly, but continuously, and it should be introduced on the down stroke, when the pump is running slowly, through the little cup provided for that purpose, and not through the air suction valves. An automatic oil cup, such as has recently come into practice, is preferable to hand oiling.

Q. 4. Explain the operation of the steam end of the pump—on an up-stroke; on a down-stroke.

A. When first admitting steam to the 9½-inch pump, if the main piston is at the bottom of the cylinder (as it usually is, due to gravity), the main valve moves to the right hand position, pulling with it the side valve and thus admitting steam to bottom of the cylinder under the piston, forcing it up; when the main piston is nearly at the top of the stroke, the reversing plate catches the shoulder on the reversing-valve rod, moving the reversing rod and valve to their upper positions, where it admits behind the large head of the main valve, forcing this main valve over to the left, carrying with it the slide valve which admits steam to the top end of the cylinder and at the same time exhausts it from the bottom end, thereby reversing the stroke of the pump.

Q. 5. Explain the operation of the air end of the pump on an up-stroke; on a down-stroke.

A. The air piston is directly connected with the steam piston, and any movement of the steam piston will consequently be transmitted to the air piston. When the steam piston moves up the air piston will, of course, go with it, thus leaving an empty space or a vacuum in the lower end of the air cylinder, underneath the air piston. Atmospheric air rushes through the air inlet, raising the lower receiving valve, and filling the bottom end of the cylinder with atmospheric pressure. At the same time the air above the air piston will be compressed. The pressure thus formed holds the upper receiving valve to its seat and when a little greater than the air in the main reservoir, the upper discharge valve will lift and allow the compressed air to flow into the main reservoir. When the piston reaches the top of the stroke its motion

is reversed, and on the down stroke the vacuum in the upper end of the air cylinder is supplied by atmospheric pressure passing through the upper receiving valve. The main reservoir pressure is held by the upper discharge valve, and the air being compressed in the bottom of the cylinder holds the bottom receiving valve to its seat, and when compressed sufficiently, forces the lower discharge valve open and passes to the main reservoir.

Q. 6. Give some of the causes of a pump running hot.

A. First, air cylinder packing rings leaking. Second, discharge valves stuck closed or the discharge passages so obstructed that the pump will be pumping against high pressure continually. Third, poor lubrication. Fourth, high speed. Fifth, discharge or receiving air valves leaking. Sixth, air piston rod packing leaking.

Q. 7. If a pump runs very hot on the road, how will you proceed to cool it?

A. First, reduce the speed of the pump, and look for leaks in the train line. Second, make sure that the packing around the piston rod is not too tight and in bad condition. Third, see that the main reservoir is properly drained. If the pump still runs hot it should be reported at the end of the trip.

Q. 8. If the pump stops, how can you tell whether the trouble is in the pump or in the governor?

A. It may be tested by opening the drain cock in the steam passage at the pump, and noting whether there is a free flow of steam; if so there is a free passage through the governor and the trouble is not there.

Q. 9. State the common causes for the pump stopping.

A. There are several reasons. First, it may be stopped by the governor being out of order. Second, the

valves may be dry and need lubrication. Third, nuts may be loose or broken on the piston rod or one of the pistons pulled off. Fourth, the reversing valve rod may be broken, or bent, or the reversing plate may be loose, or the shoulder on the reversing valve rod or on the reversing plate may be so badly worn as not to catch and perform their proper functions. Fifth, nuts holding the main valve piston may be loose or broken off. Sixth, excessive blow past the packing rings of the main valve.

Q. 10. Under what circumstances will a pump compress air in but one direction?

A. With either discharge valve broken and held off its seat.

Q. 11. How will defective air valves affect the operation of the pump?

A. Leaky air valves, like leaky air cylinder packing, cause a pump to heat badly and lose greatly in the amount of air compressed. A broken air valve causes the loss of all service of compression at that end of the pump, that is, makes it single instead of double acting. See also Answer 6.

Q. 12. How do you locate these defects?

A. By the way the pump acts. The main piston moves quickly toward a broken receiving valve and away from a broken discharge valve. The various defects all have their symptoms, which are noticed if the principle of the pump and its details are clearly understood.

Q. 13. Should an engineman observe the working of a pump on the road so as to properly report defects or repairs needed, and do you consider yourself competent to locate defects?

A. Yes.

Q. 14. If the pump stops on the road, what will you do to start it?

A. I would close the steam valve a moment and then open it quickly. If it then failed to start, it would indicate that the main valve was broken. I would also examine it in both air and steam end for defects. Be sure, first, that the governor is not defective or has not shut off the supply of steam to the pump.

THE DUPLEX AIR PUMP.

[THE NEW YORK AIR-BRAKE SYSTEM.]

Q. 1. Describe the New York Duplex Air Pump and its operation in the steam end.

A. It has four cylinders—two steam and two air; one air cylinder is double the area of any one of the other three, which are all the same size. The steam end is duplex, and the piston in each steam cylinder operates the slide valve which controls the flow of steam from the boiler into the opposite steam cylinder and out to the atmosphere. This is done by locating the slide valve for the right cylinder under the left cylinder, and for the left cylinder. under the right one, and cross the steam ports from the left valve to the right cylinder and from the right valve to the left cylinder. The valves are D slide valves which admit steam to the cylinder by the outside edge of the valve and exhaust through a cavity in the center. The seat has three ports, two steam with the exhaust port between them. A reversing valve rod is attached to the steam valve and extends into the steam cylinder; the main piston rod is drilled to clear this valve rod within it and a plate is bolted on to the steam piston in such a manner as to strike a shoulder on the valve rod

just before the stroke of the piston in either direction is completed, changing the steam valve to the opposite position in the steam chest. Both steam valves being down, when steam is turned on the right piston makes a stroke up and at the completion of the stroke changes its steam valve, causing the left piston to make a stroke up, changing its steam valve at the completion of the stroke, and causing the right piston to move down, etc. The steam cylinders are the two bottom cylinders.

Q. 2. Describe the operation of the air end.

A. The large piston compresses air into the smaller cylinder and then the latter compresses it into the main reservoir.

Q. 3. Is this a compound pump in both steam and air ends, or in the air end only?

A. Only in the air end.

Q. 4. What defects in the steam end will stop the pump? How do you locate them?

A. Chiefly the reversing apparatus—the reversing plates and rods. Would investigate until the trouble was found, bearing in mind the main valve for one cylinder regulates the steam in the other.

Q. 5. What defects in the air end will stop the pump? How do you locate them?

A. Generally broken piston rods or loose nuts. Broken or defective valves cause the pump to go "lame," but seldom stop the pump unless broken parts get into the cylinder. Remove the top heads to get at the air cylinders and examine the valves through their caps.

Q. 6. Explain how you will locate a blow of steam by the piston or main steam valves.

A. It is difficult to distinguish between leaky packing rings, leaky slide valves and worn cylinder. These parts

should be removed and examined carefully when there is a bad blow.

Q. 7. What is the cause of the pump not exhausting square or working lame?

A. Any one or more of the air valves stuck or broken or if they have much different "lift."

Q. 8. What is the effect of leaky piston rod packing in the high pressure air cylinder?

A. Any defective or leakage in the smaller or high-pressure cylinder is more serious than in the low-pressure cylinder because the pressure in the former is so much higher that the consequent loss is greater. This loss of compressed air to the atmosphere will cause the pump to run faster in order to maintain the same pressure.

Q. 9. What is the effect of leaky piston rod packing in the steam cylinders?

A. A waste of steam, obstructing the vision in the winter and causes the piston rods to cut and groove.

Q. 10. Explain how you would locate a defective air valve.

A. The general rule is this: the piston jumps toward a leaky or broken receiving valve and away from a broken or leaky discharge valve; also in the latter case the pump heats up more, as the compressed air is "churned," that is, pumped over and over again. Air blowing out of the low-pressure receiving valves is readily detected.

Q. 11. How should the air cylinders be oiled? The steam cylinders?

A. In the air cylinders use good valve oil very sparingly. Always keep good, well oiled swabs on the piston rods, as it has been proven by many careful engineers that with these practically no oil need be put into the air

cylinders. Valve oil in the steam cylinders and lubrication started directly after the pump has started. Remember the first steam admitted to a cold pump condenses and washes the surfaces clean of oil; hence oil should be supplied immediately thereafter.

Q. 12. Which air cylinder requires the most oil?

A. The smaller or high-pressure cylinder, on account of the higher temperature.

Q. 13. Explain the operation of the automatic oil cup used on the air cylinders.

A. With the oil cup filled, the pump working and the stroke of the piston upward, air is forced up through a small passage in the center of the oil cup body and cap, down inside the extended cap nut sleeve, through the oil and forms a pressure thereon. When the piston is on its downward stroke, and there is a partial vacuum in the air-cylinder, the air pressure formed on top of the oil in this cup forces the oil up inside the sleeve of the cap nut to the feed port and a small quantity of oil is then taken down through this port and sprayed into the air cylinders on each down stroke.

[THE NEW YORK ENGINEER'S BRAKE VALVE.]

Q. 1. Name the positions of the handle of this valve.

A. Release, running, positive lap, service graduating (divided into five notches) and emergency.

Q. 2. Describe the flow of air through the valve in each of these positions.

A. Release, from the main reservoir to the train pipe through large opening. Running position, from the main reservoir past the excess pressure valve (when open) to the train pipe. Positive lap, all ports closed except port

"O" to chamber "D." Service graduating, small opening from the train line through the main slide valve to the atmosphere, which opening is finally closed by the graduating slide valve when the certain reduction has been made. Emergency position, a large direct opening between the train line and the atmosphere.

Q. 3. What is the duty of the supplementary reservoir? In case the connections to this reservoir are broken or leaking badly, what will you do, and how will you make a service reduction in the train pipe?

A. To enlarge chamber "D" plug it up and make service reductions in the first or second graduating notch, bringing the handle back to positive lap when by the gauge you found a sufficient reduction has been made.

Q. 4. By what pressure is this reservoir charged?

A. Train pipe pressure.

Q. 5. Explain the difference in the manner of charging this reservoir in the style "A" pattern of brake valve and in the style "B," the later pattern of valve.

A. With the style "A" valve the handle must be left a moment or moved slowly over running or positive lap positions in order to fill this supplementary reservoir and thus be ready for service graduations. With the style "B" valve the equalizing piston returns to its normal position no matter in what position the brakes have previously been released.

Q. 6. What is the duty of the equalizing piston? Explain its operation in a service reduction.

A. To stop the discharge of air from the train pipe without causing the release of any of the head brakes on the train. When the train pipe pressure in chamber "A" becomes enough less than that in chamber "D," the piston is gradually moved and closes the graduating slide valve.

Q. 7. How will you distinguish the new pattern of brake valve from the older one?

A. The cap to chamber "D" has a larger projection due to the provision made for the vent valve with style "B."

Q. 8. Explain the operation of the style "A" valve in a service application. In an emergency. In a release of brakes and re-charging the supplementary reservoir.

A. With the style "A" valve, if the previous release had been made in running position instead of full release, the equalizing piston would not return to its normal position because no air had been exhausted from chamber "D," hence no response would be had to the next service application until the handle had been moved to the next graduating notch beyond one used in previous application. Also, as explained in Answer No. 5, care had to be taken to fill chamber "D" and the equalizing reservoir between two applications. Both types of valves work alike in emergency application.

Q. 9. Explain the operation of the style "B" valve in an application. In a release of brakes.

A. The style "B" valve works practically the same in an application of the brakes, only that in case of a second application after release there is no trouble in keeping the equalizing reservoir properly charged and the graduating feature is reliable in all its notches for repeated applications.

Q. 10. Why is it not necessary to move the handle of the valve to lap position between reductions in a service application?

A. Because the graduating slide valve laps the ports by its automatic movement received by the graduating piston after the reduction corresponding to the service notch has been made.

Q. 11. What are the plugs for that are in the cap of the brake valve?

A. So that the main slide valve can be oiled without taking the brake valve apart.

Q. 12. How will you test for leaks in either pattern of brake valve?

A. With valve "A," to test for leaky main slide valve place the handle in the last service notch, close the stop-cock under the brake valve and watch for any rising of the black hand in the gauge. With the style "B" valve, place in emergency position, then to positive lap, close the stop-cock and notice if the black hand rises. To test the small cut-off or graduating valve after ascertaining that the main slide-valve is tight, make a reduction in the second service notch, then close the stop-cock. If a blow is heard at the exhaust port and the black hand falls slowly, the cut-off valve is leaking.

[THE GOVERNOR.]

Q. 1. What is the duty of the pump governor?

A. To properly regulate the air pressure in the main reservoir.

Q. 2. Explain how the governor operates.

A. The governor is an automatic arrangement for admitting and closing off steam to the air pump, and is actuated by air pressure. The steam valve, which shuts off and opens up the steam passage way to the pump, is controlled by an air piston and spring. When air pressure is admitted above the piston, it forces the piston down, closing off the steam to the pump. When the air pressure is exhausted from above the piston, the spring forces the piston up and allows steam pressure to pass

to the pump. The admission and exhaust of the air to this piston is controlled by a diaphragm and spring. The air from the main reservoir enters the body of the governor underneath the diaphragm, which is held by a spring of given tension, depending on the pressure desired in the main reservoir. While the main reservoir pressure is less than the pressure the governor is set for, this diaphragm is held down by the spring, and the air can pass no further than a small pin valve attached to it, but when the main reservoir pressure overcomes the tension of the spring, it raises the diaphragm, unseats the pin valve and allows the air to flow to the top of the air piston, shutting off the pump. During the time the air is acting on this piston some of it escapes through a leakage port or vent hole, which is always open. When the main reservoir pressure drops below that to which the spring is adjusted, the spring forces the diaphragm down, seating the pin valve and allowing the air on top of the piston to escape to the atmosphere, through the small vent port.

Q. 3. By what air pressure is the governor operated when using the D-8 brake valve? When using the G-6 valve? When using the New York brake valve?

A. With the D-8 valve, by train line pressure. With the F-6 or G-6 valve, by the main reservoir pressure. New York, by the train line.

Q. 4. By what pressure is the duplex governor operated in high speed service? By what pressure in ordinary service?

A. The governor tops are adjusted for 90 and 110 pounds and the two feed valves are set for 70 and 90 pounds. To operate the low or ordinary pressure feature, the handle of the reversing cock is turned to the

left, this cuts out the 110 pound governor and 90 pound feed valve and renders operative the 90 pound governor and 70 pound feed valve. By reversing the position of the reversing cock handle the low-pressure parts are cut out and the high-pressure parts cut in; but the small stop cock in the governor pipe must also be closed.

Q. 5. What is the object of the relief port in the governor? Why should it be kept open?

A. If this port is not kept open, the air pressure which holds the piston down cannot escape when the diaphragm valve closes and consequently the governor will not operate the pump properly.

Q. 6. If the pin valve leaks, what effect will it have on the pump?

A. It will allow a certain amount of air pressure to flow in on top of the air piston. If the leak is greater than the escape from the little leakage port, the under pressure will accumulate, and cause the governor to slow down or completely stop the pump.

Q. 7. How can you detect leaks in the governor?

A. By disconnecting the upper from the lower section of the governor, then attaching the air pressure connection, turn the air pressure under the diaphragm. If it raises with the proper pressure and opens the port the escape of air will be readily noticed. Should it not be raised or the port be closed by dirt, it would be in that section, this will also show if the diaphragm leaks. I would then inspect the lower section.

Q. 8. Where would you look for the cause if the governor allowed the pump to raise the pressure too high?

A. The main reservoir pressure may not reach the governor, due to the stoppage in the pipe, or in the

union at the governor. This may also be due to the space on top of the diaphragm being filled with dirt. If the air is getting to the diaphragm valve, and is so indicated by the blow at the leakage port, the trouble must then be due to the drip pipe being stopped up or frozen, thereby preventing the air and steam, which leak in under the air piston, from escaping.

Q. 9. Where, if the pump stopped when the pressure was too low?

A. If the pump was not getting steam it would probably be due to the pin valve gummed up or dirt under it; the detector hole or leakage port in the side of the governor would then blow. Once in a great while the piston and steam valve have been known to stick closed but very rarely.

Q. 10. What effect does it have on the pump if the drip pipe is stopped or frozen up?

A. The governor cannot then act to shut off the pump and too high pressure will be pumped into the main drum.

[THE MAIN RESERVOIR.]

Q. 1. What is the main reservoir used for?

A. The main reservoir is for the purpose of storing a supply of air in advance of its use for all purposes.

Q. 2. Why does water accumulate in the main reservoir, and how often should it be drained?

A. The atmosphere contains moisture which is precipitated by compression and settles in the main drum which should be drained daily and at a time when the reservoir is warm enough to be certain no ice could remain therein.

Q. 3. What is excess pressure, and what is it for?

A. Excess pressure means simply "additional" pressure or more pressure in the main reservoir than in the train line. For example, if the train line has 70 pounds and the main reservoir 95 pounds, there would be 25 pounds of excess pressure. Again, if the train line had 90 pounds and the main reservoir 115 pounds there would still be 25 pounds of excess.

ENGINEER'S BRAKE AND EQUALIZING DISCHARGE VALVE.

Q. 1. Name the different positions of the brake valve and trace the flow of air through it in each position.

A. Full release, running position, lap, service application and emergency application. In full release there is a large direct communication between the main reservoir and the train pipe. In running position the air passes from the main reservoir indirectly to the train pipe, that is through the ports and passages of the excess-pressure valve or through the feed-valve, as the case may be. In lap position all ports are closed. In service application first the air from the equalizing discharge reservoir and cavity "D" escapes to the atmosphere, then, when the equalizing discharge piston raises, the air from the train pipe escapes to the atmosphere through the train line exhaust elbow. In emergency position a large direct opening is made between the train pipe and the atmosphere.

Q. 2. Where does the main reservoir pressure begin and end? Where does the train pressure begin and end?

A. The main reservoir pressure begins at the pump discharge pipe and ends at the connection to the brake

valve. The train pipe pressure begins at the brake valve and extends to the rear cock on the train, with branches to the triple valve under each car, the tender, and the engine.

Q. 3. Explain the effect of a cut rotary valve or seat.

A. A leaky rotary valve or seat usually causes a loss of excess pressure in running position and releases the brakes in lap position.

Q. 4. How do you regulate the excess pressure with each form of brake valve? How do you clean the valves?

A. With the 1889 (D-8) brake valve, by the excess pressure spring; with the later forms of brake valves, by the spring in the feed-valve attachment. Clean the valves and their seats by waste or friction from a soft piece of wood—never oil them when replacing.

Q. 5. How do you apply and release the automatic brake?

A. The automatic brake is applied by reducing the train pipe pressure below that in the auxiliary; it is released by increasing the train pipe pressure above that in the auxiliary. The brake valve is the valve to properly perform these functions, when everything is in working order.

Q. 6. What can be learned by noticing the discharge of air from the train pipe exhaust?

A. The length of the train line, that is, approximately the number of cars of air. By watching this exhaust it can also be determined if, in testing brakes, one defective triple sets quick action; third, in releasing brakes it can be told if you only have the lone engine.

Q. 7. What is the duty of the small reservoir con-

nected to the brake valve? If the pipe leading to this reservoir is leaking badly or broken off, what will you do?

A. It is for the purpose of enlarging chamber *"D"* without making a great bulky brake valve in the cab. Plug up this pipe or put in a blind gasket, also plug the train line exhaust nipple and use emergency position carefully, as with the old three-way cock.

Q. 8. Where is the first air taken from in making a service stop? Where does it blow out? Where next?

A. From chamber *"D"* and the equalizing reservoir. It blows out of the preliminary exhaust. Next, the train pipe pressure escapes from the train line exhaust nipple.

Q. 9. Does air ever blow out of the train pipe exhaust when releasing the brake? Why?

A. Yes, with a lone engine or very short train, in which case the train line charges more rapidly than chamber *"D"* and the equalizing reservoir, thus causing piston 17 to raise.

Q. 10. What pressure do the red hand and black hand of the gauge indicate?

A. Red hand—main reservoir; black hand—chamber *"D"* pressure.

Q. 11. Does the black hand of the gauge also show the train pipe pressure at all times?

A. No, only when chamber *"D"* and the train line are connected, as in full release and running position. On lap or in service positions at the instant the train line exhaust starts or stops, they are also practically equal.

Q. 12. What will be the result of leaving the handle of the brake valve in full release position too long and then moving to running position?

A. Brakes are likely to drag due to temporarily shutting off all supply of air to overcome the leaks.

Q. 13. How is the train pipe pressure regulated with .ch type of brake valve?

A. By the governor with the 1889 (D-8) brake valve; ' the feed-valve attachment with all later types of 'ake valves.

Q. 14. In making a service application what should e first reduction be?

A. From 5 to 8 lbs, depending upon the length of the ain.

Q. 15. What reduction from seventy pounds train pe pressure will fully apply the brake? Why?

A. About 20 pounds; because that amount from the ıxiliary reservoirs will equalize with the pressure in e brake cylinders at about 50 pounds.

Q. 16. How do you handle the brake valve to apply e brake in the emergency?

A. It should be thrown to full emergency position :d left there.

Q. 17. How do you handle the brake valve in the se of a bursted hose?

A. Place the handle on lap. If the trainmen could t find the burst hose, I would frequently throw a ıve of air into the train pipe (in running position or rtial release) so as to aid them.

Q. 18. In case the train breaks in two?

A. Place the brake valve on lap until the rear cock the first section is closed; then release and as soon as ese brakes are off, place the handle again on lap to t pressure to release the rear portion of train when upled up. Do not recharge to full pressure until the ıole train is coupled up.

Q. 19. When the train is backing up and a tail se is used on rear end to apply brakes?

A. Always carry the valve in running position when the tail hose is being used. Never throw it to full release unless the train stops and some brakes fail to release.

Q. 20. Do leaks in the brake valve affect the operation of the brakes?

A. Yes. If air leaks to the atmosphere it will effect the reduction desired. If it leaks from the main reservoir to other ports it may release the brakes or make the service application position of no effect.

Q. 21. Name the defects in the brake valve and explain how you would locate them.

A. Leaky rotary valve (or body gasket) place the valve in service position, bleed the engine and tender auxiliaries and place the rear tank hose in a bucket of water. Air bubbles in the water will indicate this leak. If the rotary and body gasket are tight, loss of excess means dirty or cut feed-valve or broken feed-valve gasket. Leaky packing ring in piston 17 (the equalizing discharge piston) makes the gauge reduce slower and the black hand recoil after a considerable reduction. A leak in chamber "*D*" or its connections (the gauge and the equalizing reservoir) causes the train line exhaust to blow and the brakes to set on lap position. These are the main defects and "symptoms."

Q. 22. In what manner can you remedy these defects?

A. Carefully tighten the bolts or unions where gaskets are leaking and clean any dirty valves without scratching them; after that is done it is better to handle the valve carefully until the terminal is reached and report the repairs needed in detail.

[THE STRAIGHT AIR BRAKE.]

Q. 1. What additional parts are needed on an engine and tender to have the straight air brake in connection with the automatic brake?

A. The straight air brake is designed to operate on the engine and tender alone, and not on the cars of the train. To operate the combined automatic and straight air brake, extra parts as follows should be supplied: Reducing valve for the straight air system, set at 45 pounds; an engineer's straight air brake valve; a double seated check valve for the driver brake cylinder; a double seated check valve for the tender brake cylinder; a safety valve, set at 53 pounds, one for the driver brake cylinders and one for the tender brake cylinder; and a straight air brake hose connection between the engine and tender.

Q. 2. What is the duty of the double check valve, and how does it operate?

A. To prevent air escaping from the brake cylinder through the triple exhaust port while the straight air is applied, also to prevent the air escaping from the brake cylinder through the straight air brake valve exhaust port while the automatic brake is applied. It consists of a double piston with a leather face on each. When the automatic brake is applied the piston is forced to such a position as closes the straight air side and at the same time opens a set of ports that admits the air to the brake cylinder. When the straight air is applied just the reverse occurs and air from the main reservoir, through the straight air brake valve is admitted to the brake cylinders.

Q. 3. What pressure should the reducing or feed

valve used with this brake be set at? The safety valve?

A. Reducing valve set at 45 pounds. Safety valve set at 53 pounds.

Q. 4. How do you operate the straight air brake?

A. By placing the handle of the brake valve forward in application position, the application valve is opened admitting air from the main reservoir to the brake cylinders; by placing the handle of the valve back in release position, the release valve is opened allowing the air in the brake cylinders to flow to the atmosphere. Lap position is intermediate and in this position both valves are closed.

Q. 5. In what position should the automatic brake valve be when releasing the straight air brake?

A. The automatic valve should be carried in running position with excess when using the straight air brake.

[THE TRIPLE VALVE.]

Q. 1. What is the duty of the triple valve?

A. The duty of the triple valve is, first, to charge the auxiliary reservoir, second, to set the brakes by allowing auxiliary pressure to flow to the brake cylinder, and third, to release the brakes by allowing the pressure in the cylinder to escape to the atmosphere.

Q. 2. By what is it connected to the brake valve?

A. By the branch pipe and the train line with hose.

Q. 3. Explain the duty of the triple piston, the slide valve and the graduating valve.

A. The duty of the triple valve piston, is, by variation of pressures on its two sides, to move the slide valve on its seat to the application, graduating, and release position, and to open and close the feed groove

in the piston bushing. The function of the slide valve is, by its movement due to the triple valve piston, to make connection between the auxiliary reservoir and brake cylinder, applying the brake, and to make connections between the brake cylinder and the atmosphere, releasing the brake. The function of the graduating valve is, from its movement given by the triple piston, to admit pressure gradually from the auxiliary reservoir to the brake cylinder in response to reductions made in the train pipe pressure.

Q. 4. How many kinds of triple valves are in use on this road?

A. Two, the plain type and the quick action type, or according to the fact.

Q. 5. Describe how each kind operates.

A. With the quick action type, a sudden reduction of pressure in the train pipe will cause the triple piston and its parts to be moved to quick action application position, which first throws into operation the emergency feature of the triple, admitting train line pressure to the brake cylinder, after which auxiliary reservoir pressure is permitted to pass to the brake cylinder, and consequently a higher pressure is obtained than in a full service application of the brake. With the plain type any sudden reduction merely moves the parts to their extreme position but allows no other than auxiliary reservoir pressure to flow to the brake cylinder.

Q. 6. Explain where the air comes from that enters the brake cylinder in a service application. In an emergency application. With each kind of triple valve.

A. In service application with either type of triple valve the air that enters the brake cylinder comes from the auxiliary reservoir; with the quick action triple only

does part of the train pipe air first enter the brake cylinder quickly, later followed by the auxiliary pressure.

Q. 7. How do you cut out a triple valve so its brake will not operate?

A. The old style plain triple, by turning the handle down obliquely to about 45°. With the later style and all quick action triples, by closing the stop cock in the branch pipe. You should then bleed the auxiliary reservoir.

Q. 8. If a triple valve does not apply the brake at the proper time, where will you look for the trouble?

A. If the auxiliary is charged, the triple valve is probably frozen or stuck or the packing ring worn badly, or the brake cylinder itself leaking badly. If the auxiliary has not charged the feed groove may be closed or the reservoir itself be leaking badly.

Q. 9. If the brake will not release, where will you look for the trouble?

A. Retainer turned up or its pipe stopped up; triple piston packing ring worn; triple strainer stopped up or triple frozen.

Q. 10. Name the common defects of the triple valve and explain how you locate them.

A. Triple valve frozen or stuck, packing ring leaking, etc., located as above. Emergency gasket leaking—cut the car out underneath and the brake will set quick action. Slide valve dirty or leaking—blows through the exhaust or retainer but will not cause emergency as last stated. Brake fails to release on long train, usually the piston packing ring or cylinder bushing worn badly.

[THE HIGH SPEED BRAKE.]

Q. 1. Name the complete parts that are added to the ordinary brake to make the latter a high speed brake.

A. Two feed-valve attachments with reversing cock, a Siamese fitting with two pump governor tops, and one high speed automatic reducing valve connected by piping to each brake cylinder on the engine and cars.

Q. 2. How much pressure is carried in train pipe and auxiliaries with high speed brake?

A. 110 pounds.

Q. 3. How would you change from low to high, or from high to low pressure?

A. Turn the reversing cock so the 70 pound feed-valve would regulate the train pipe pressure and cut in the cock to the low pressure governor top; change both these cocks and you are ready for the high speed brake.

Q. 4. How many pounds train pipe reduction in a service application will give a fully applied brake?

A. About 20 pounds.

Q. 5. At what pressure will the auxiliary reservoirs and brake cylinders equalize with an emergency application using the high speed brake?

A. At about 85 pounds with a 7-inch piston travel.

Q. 6. Explain in a general way the operation of the reducing valve in service and in emergency.

A. The valve consists of a piston and stem whose downward movement is regulated by the adjusting spring. A small slide valve with a triangular escape port is attached to the upper sidc of the piston. If the adjusting spring is set at 60 pounds, and an emergency application of the brake be made, the piston will descend when 60 pounds has been accumulated in the brake cyl-

..nder, and the apex or smallest part of the triangular port will permit brake cylinder pressure to pass through it and escape to the atmosphere; as the brake cylinder pressure reduces, the piston will gradually move up a larger part of the triangular port, thus increasing the opening for the escape of brake cylinder pressure to the atmosphere. When the brake cylinder pressure has blown down to 60 pounds, the port will be closed, shutting off further escape of brake cylinder pressure to the atmosphere. In service application, the larger portion of the triangular port will permit brake cylinder pressure to escape to the atmosphere when 60 pounds has been accumulated in the brake cylinder, thus blowing down the pressure quickly and preventing more than 60 pounds being accumulated in the brake cylinder in service application.

Q. 7. If a train with high speed brakes should pick up a car not equipped with same, what should enginemen do?

A. Unless a safety valve is at hand to screw into the cylinder oil hole on the car, the only perfectly safe way against wheel sliding in case of emergency would be for the engineer to discontinue the use of the high speed brake on the whole train.

Q. 8. When a car that is equipped with an ordinary brake is coupled to a train using the high speed brake, what must be done with this car to run it with the high pressure?

A. Screw a safety valve into the cylinder of this car.

Q. 9. How many full service applications can be made without recharging, and have left as much pressure as is used with the ordinary quick action brake?

A. Two. The first one from 110 to 90; the second, 90 to 70.

Q. 10. Should the emergency be used with the high speed brake at a speed of less than forty miles per hour? Give reason.

A. It should not, as the wheels will more than likely be slid for the automatic reducing valves do not have time to release the extra pressure before the speed is so slow that the wheels will slide.

THE WATER BRAKE.

Q. 1. Explain the principle upon which the water brake works.

A. When a locomotive is reversed the cylinders form powerful compressors, tending to retard the engine greatly but at the same time it is liable to cut the cylinders besides forcing air, gases, and smoke through them into the boiler. hence a small jet of hot water is piped from a globe valve in the cab (which valve is on a level with the crown sheet) to the two exhaust passages in the cylinder saddles.

Q. 2. Where is it intended the water brake should be used, and what is the object of using it instead of air driving wheel brakes?

A. In mountain service only, its object being to hold the train while recharging the auxiliaries with air; it also allows the driver brakes to be released before the tires get so hot as to become loose.

Q. 3. What must be done with air driver brakes before water brake is put into action?

A. They should either be cut out or the bleeder left open.

Q. 4. In what position should reverse lever be placed before putting water brake into action?

A. In forward motion until steam is properly regulated through watching the open cylinder cocks, then the reverse lever should be immediately placed a few notches back of the center, as desired.

Q. 5. Should cylinder cocks be open or closed?

A. They should be left open.

Q. 6. Explain how the water brake is then applied and released.

A. By the opening and closing of the water valve and the movement of the lever to reverse or to forward motion.

Q. 7. How can you tell when water brake valve is opened sufficiently?

A. By the color of the steam as it escapes from the cylinder cocks before reversing.

Q. 8. How is the power of the water brake regulated?

A. By hooking the reverse lever farther back in the quadrant it is increased, and vice versa.

Q. 9. At what speed is the water brake most efficient?

A. At from 5 to 12 miles per hour.

Q. 10. What speed should not be exceeded when water brake is put into operation?

A. Not more than 16 to 18 miles per hour.

TRAIN AIR SIGNALING.

Q. 1. How does the air signal equipment operate?

A. Air pressure from the main reservoir is supplied at a reduced pressure through the reducing valve to the signal line. On each car a branch of the signal line leads through a cut-out cock to the signal discharge valve

above the door; a branch on the locomotive leads to the whistle valve. Any sudden reduction in the signal line releases the whistle valve and blows the whistle.

Q. 2. What pressure should be carried in the signal line? How do you know you have this pressure?

A. Forty pounds. By a test gauge or by placing the brake valve in full release, shut off the pump and open the rear train line cock until the whistle blows; then the red pointer of gauge shows the signal line pressure approximately.

Q. 3. What causes the signal whistle to blow each time the brake is released?

A. Dirty reducing valve which lets full main drum pressure accumulate in the signal pipe and when the brake is released, the flow of air from the signal pipe back to the main reservoir blows the whistle.

Q. 4. If the whistle gives a weak blast where would you look for the trouble?

A. First see that the whistle was clean and properly adjusted; next see if opening the rear signal cock on the engine a little would give good whistle; if not the whistle valve or pipe may be stopped up. If the apparatus on the engine is all right, the car discharge valve or strainer may be stopped up or a very bad leak exist in the signal line on the train.

Q. 5. What makes it repeat the signal?

A. Too short and quick an opening of the discharge valve in the middle of a long train sometimes, or the whistle valve stem not fitting properly.

Q. 6. Will a leak in the signal line affect the working of the signal valve? Explain.

A. Yes. You can give signals from cars ahead of the leak better and in more quick succession than from

cars back of the leak. A continuous leak keeps the reducing valve open all the time, hence to blow the whistle you have to reduce the signal line pressure faster than it is being supplied, which is difficult on a long train especially.

Q. 7. Where would you look for the trouble if the signal pipe would not charge?

A. In the reducing valve. It would probably be found to be dirty, or the adjusting spring may not be set, or the signal cut-out cock may be closed at the reducer connection.

SUPPLEMENTARY QUESTIONS AND THEIR ANSWERS.

Q. What would be the best method of testing for a leaky exhaust pipe joint or nozzle joint?

A. It is hardly practical to make a good test for leaky exhaust pipe joints or nozzle while on the road. However, the front end may be opened while the engine is working slowly, and it is possible that the leaks will show themselves or that the absence of any sparks around the joint at the bottom of the nozzle stand will indicate leakage at that point. To make a thorough test the exhaust tip must be plugged and then, with the throttle open, the reverse lever should be moved from the forward to the back corner several times, using water pressure when available.

Q. How would you proceed in case of a hot bearing?

A. If for any cause a bearing becomes hot while on the road, the first thing to do is to see that the oil hole is open. Then make sure that the bearing receives plenty of lubrication, using valve oil, soap or graphite, or a mixture of these lubricants. Proper lubrication is the best treatment for a hot bearing and water should not be used if the bearing is very hot.

Q. In the event of a steam chest becoming cracked, what would you do?

A. If a steam chest cracks it can usually be made tight enough to get in with by loosening up on the nuts on the studs holding down the steam chest cover, and

placing wedges between the steam chest and the studs in such manner as to draw the cracked sections together. A brake-shoe key makes a convenient wedge for this purpose. After the parts are tightly wedged together, the nuts should be tightened up again, and in most cases the joint will be tight enough to get in with.

Q. What would you do if the steam chest should be broken?

A. If a steam chest breaks the only thing to do is to block the steam admission ports to the steam chest. A fish plate fastened to some of the studs will hold the blocking down if the steam chest is partly demolished.

Q. In case a link lifter or arm should become broken, what would you do?

A. A block must be placed between the top of the link block and the top of the link that will give the valve sufficient cut-off to bring the train in with. Another block should be placed between the bottom of the link block and the bottom of the link on the good side to prevent the possibility of accidentally reversing the engine. If it is desired to reverse the engine the blocking must be changed accordingly.

Q. How would you proceed in the event of a broken reverse lever or reach rod?

A. With a broken reverse lever or reach rod, one block placed between the top of the link and the top of the link block so as to give the desired cut-off is all that is necessary, unless it is desired to reverse the engine, in which case a long block must be used between the top of the link block and the link, and a short block between the bottom of the link block and the link.

Q. What course would you pursue in case of a broken or bent piston, cross-head, connecting rod or crank pin?

A. If a piston or piston rod is broken or bent, remove the broken parts, clamp the valve in the center of its seat, and proceed without taking down the main rod unless the guides have been injured.

If the crosshead, connecting rod, or crank pin is bent or broken, remove the broken parts, clamp the valve in the center of its seat, block the piston and what remains of the crosshead securely, and proceed on the other side.

Q. If the safety valve spring should become broken, what would you do?

A. If a safety valve spring breaks, after the pressure has all been relieved the valve can be screwed out and a plug of wood fitted in the valve in such manner that when the valve is screwed back into place again it will hold the pressure. The other safety valve must, of course, be in condition to relieve the boiler of excessive pressure.

Q. How could you manage to bring in your engine in case of a broken front end or stack?

A. The front end of an engine, when broken, can always be boarded up sufficiently to allow enough draft to be furnished to bring in the light engine.

If the stack is knocked off it will be hard to get very much draft on the engine, although, by fastening a barrel or something similar over the opening, draft enough can be secured to bring in the light engine.

Q. In case you should break a frame between the cylinder and the main driver, what could be done in order to get the engine to the shop?

A. When a frame is broken between the main driver and the cylinder, it is not safe to try to do any work with the engine. Unless the rules of your road say otherwise, disconnect the valve stem on the broken side

and clamp the valve. Proceed on the other side, using a light throttle.

In case the engine is to be towed in, it should not be placed in a train as the strain or shock at either the head or rear end of the train is liable to do damage.

Q. In case a cylinder key should work loose or become lost entirely, what would you do?

A. If there is a loose or lost cylinder key, it should immediately be replaced to avoid serious damage to the cylinder saddles. If nothing is at hand which can be used as a temporary wedge, the engine should be run light to the nearest town and a wedge obtained from some blacksmith, which can be used, and by the use of which it would be safe to bring the train in.

Q. What would you do with a broken frame if the break should occur back of the main driver?

A. If the frame is broken back of the main driver, it is not advisable to try to handle any part of the train, but the engine can be brought in light without doing any damage.

Q. How would you proceed if a side rod broke?

A. In case of broken side rods, remove broken parts, and always remove the corresponding rods on the opposite side of the engine. If the corresponding rods on the opposite side of the engine are not removed it is almost certain that in passing over a frog or bad place in the track, or if the engine slips, that the wheels will commence turning in opposite directions, with the result that the rods will be all twisted up and the pins bent or broken.

Q. Would it be safe to proceed with a consolidation engine having the eccentrics fixed to the axle ahead of the main drivers, in case of a broken intermediate con-

necting or side rod? If not, why? What would you do in a case of this kind?

A. It is not safe to take any chance in this case, as slipping the engine or moving the engine under its own steam will allow the engine to get ahead of the valve gear and produce disastrous results. The engine should be prepared for towing in.

Q. In case you should break a forward tire on a ten-wheel engine, what would you do to enable the engine to proceed?

A. Remove the broken parts, run the wheel with the broken tire up on a wedge, remove the cellar and block between the axle and the pedestal brace, and provide for lubricating this axle as it turns on the blocking. Then block between the spring saddle and the top of the frame and in this way the weight will be taken off from the box, the wheel will be swung high enough to clear the rail and the weight of the journal carried on the blocking which is in place of the oil cellar. Cut out the driver brake to avoid any danger which might come due to its use.

Q. In case you find it necessary to raise a wheel while out on the road where jacks were not available, how would you accomplish it?

A. A wheel can be raised when jacks are not available by running it up on a wedge.

Q. How could you determine whether or not the wedges were set up too tight? If the driving box should stick so that it could not be pulled down by means of the adjustment nut, how would you proceed to force it down?

A. If a driving box is stuck, due to the wedge being set up too tight, the box will invariably run hot and the engine will ride very hard.

If the wedge can not be pulled down by means of the nut and screw used for adjustment, it may then be gotten down by prying or sledging, and can many times be loosened by running that wheel over a coal pick or bit of iron and letting it drop off, thus jarring it loose.

Q. How would you be able to designate what wheel or truck on the engine or tender was meant in reporting work to be done thereon?

A. Some roads have definite instructions about designating the different driving wheels, truck wheels, and tank wheels. If no such rule is in force on your road, the best plan is to explain definitely which wheel. For instance, "The back engine truck wheel on right side."

Q. State what defects cause an engine to pound?

A. Among the various things that will cause an engine to pound may be mentioned, brasses improperly keyed; wedges not set up tight; broken frames; cylinders loose on frame; crossheads or guides not properly lined up; loose pistons; pistons overtraveling; brasses too large for pins or journals, etc.

Q. How could you locate a pound if the defect existed in the driving box wedges or the rod brasses?

A. A pound in driving boxes or rod brasses can be located by blocking the engine on the quarter and, with the throttle open, throwing the reverse lever from forward to back gear. This will show up any lost motion in the rods or boxes.

Q. When is it necessary to report the crosshead or guides to be lined up?

A. Crossheads and guides should be reported to be lined when they have worn down so much that there is enough lost motion so they are beginning to pound. Experience is the only teacher in this respect.

Q. When is it advisable to report driving box wedges lined up?

A. Driving box wedges should be reported to be lined when they do not set the box up tight when they are screwed clear up.

Q. When would you consider it necessary to have your rod brasses filed?

A. Rod brasses should be reported to be filed when they are keyed line and line or brass and brass together.

Q. Under what conditions would you think it necessary to have your rod brasses lined?

A. Rod brasses should be reported to be lined when driving key clear down does not bring the brasses tight against the pin.

Q. State when in your opinion it is necessary to report lost motion taken up between engine and tender?

A. Whenever there is any.

Q. Upon what principle does the locomotive injector work?

A. In general, the working of an injector may be described as follows: Steam of a certain pressure is allowed to flow through a nozzle which gives to the steam a high velocity. This steam, on leaving the nozzle, passes across a space which is in connection with the feed water supply, and passing across this space enters a second nozzle known as a combining and condensing tube. The passage of the steam at high velocity across this space carries with it any air the space may contain, much as a train passing along at high speed carries with it any dust and papers which lie in its path. In other words, this passage of steam across this space carries a vacuum above the feed water and the water rises to fill this vacuum, coming in contact, in this manner, with the jet

of steam and condensing it. The steam being arrested in its passage imparts its velocity to the water and the water and condensed steam flow together through the combining and condensing tube and through a delivery tube against the check valve. The combining tube is shaped like a fire-hose nozzle so that any steam leaving it leaves it at a high velocity, and this jet of water striking the check valve at a high velocity has sufficient force to raise the check and force its way into the boiler. The pressure against which an injector will work depends entirely on the initial pressure of the steam and the construction of the tubes in the injector.

Q. What would be the probable cause if your second injector failed to work? What treatment should the injector receive to overcome such failure?

A. The second injector generally fails because it is not used often enough to keep it in proper working order.

To obviate this failure the second injector should be used part of the time during each trip made with the engine.

Q. What points of advantage does the combination boiler check possess over the ordinary form of check valve?

A. A combination boiler check has one great advantage over the common form of check, due to the fact that in case the check sticks open the escape of the pressure from the boiler can be prevented by closing the hand valve of the combination check.

Q. In case the injector should fail to work while on the road, what should be done immediately? How would you proceed to locate the trouble?

A. If an injector stops working while on the road,

fter starting the other injector the trouble with the rst one can be ascertained. The injector may not prime r it may prime all right but fail to force, or it may both rime and force but still fail to take up all the water. If he injector fails to prime it is due to one of two causes: Either there is not a free supply of feed water to the njector or else the proper vacuum is not being formed n the injector. Make sure there is water in the tank, hat the tank valve is open, that the strainer and feed ipe are open, and that there are no leaks in the feed ipe of sufficient size to destroy the vacuum. The proper acuum may not be formed in the injector, due to the act that there is an obstruction in some of the tubes or hat the boiler check valve is leaking badly. If the inector primes but will not force, it may be that while here is some water being supplied to the injector, still here is not enough to condense all the steam or it is ossible that the tubes are out of line or full of scale, r that the line check or boiler check are stuck shut. If he injector primes but does not pick up all the water, egulating the steam valve and water valve to give the ight proportion of steam to water will usually overcome his difficulty.

Q. If the tank valve should become disconnected, how ould you overcome the difficulty without stopping?

A. A disconnected tank valve can be opened by blowng steam back through the feed pipe.

Q. If complaint is made that the cars were not proprly heated and your steam gauge registered the required ressure, how would you proceed to locate the cause?

A. Open steam valve at rear of tank to make sure hat there is no obstruction in the steam pipe on the ngine or tank, and if there is no obstruction there and

the gauge indicates proper pressure, the trouble is on the train.

Q. What arrangement is made in the steam-heat reducing valve whereby it is possible to control the pressure?

A. In the steam-heat reducing valve there is a diaphragm which is held in position by a spring, and which is connected directly to the steam admission valve from the boiler to the train pipe. The spring has a sufficient tension to hold the diaphragm down, which in turn holds the steam valve to the train pipe open. This tension is regulated by hand to give any pressure desired. When steam is turned into the valve it flows directly through this open valve into the train line, but in passing into the train line it also is directly in communication with the bottom of this diaphragm, and when the pressure in the train pipe is sufficient to overcome the tension of the spring holding the diaphragm down it forces the diaphragm back again into its normal position, which in turn shuts off the steam valve to the train pipe, and in this manner the pressure is regulated to any amount desired in the train pipe, for when the pressure again falls below what the tension of the spring is set to, the spring forces the diaphragm and valve open again, and this process of opening and closing the valve is repeated, thus maintaining a constant train-pipe pressure.

Q. State what you would regard as abuse of an engine.

A. Slipping an engine badly; handling the injectors improperly; allowing careless firing that is liable to start flues leaking; allowing the engine to run with the wedges down or the rods pounding badly; not paying proper attention to the lubrication of the engine; or anything of a similar nature.

Q. What is the best course to prevent accidents and engine failures?

A. By careful inspection and handling of the engine.

Q. What final duties should an engineman perform before leaving his engine?

A. The engine should be carefully inspected and all necessary work should be reported.

Q. Upon arrival at a terminal, what precautions should an engineer take to ascertain the condition of his engine at the end of the run?

A. The engine should be thoroughly inspected from front of pilot to back of tank. The manner of inspecting the engine depends altogether on the man who does the inspecting, but for a man to make sure that his engine is all right at the completion of a run, he must inspect everything thoroughly. Firebox for leaky flues or leaky crown bolts, wheels, tires, boxes, wedges, pedestal braces, driving springs, hangers and equalizers, eccentrics, rods, etc.; in fact, every part of the engine must be looked at to make sure it is all right.

Q. When reporting work on an engine, is it sufficient to state in a general way the nature of the defect to be remedied, such as "engine blows," "pump won't work right," "injector don't work right," etc., and if not, how should work be reported?

A. No. A sufficient explanation of what is wrong should be given so that there will be no question in the minds of the repair men about what work is necessary to be done.

*DON'TS

FOR ENGINEERS AND FIREMEN.

"FIRST. *Don't* think because you are only one engineer or fireman, that what you do does not amount to much. It is the little drops of water that make the mighty ocean, and the little grains of sand that make up this earth of ours; so each individual, in the aggregate, can do a great deal. If each engine crew saves one-quarter of a ton or five hundred pounds of coal, this on a thousand locomotives would result in a daily saving of two hundred and fifty tons, or in round figures $157,000 a year.

"SECOND. *Don't* neglect being at roundhouse in ample time to examine the firing tools on the engine before leaving the roundhouse. See that your ashpan, grates and flue-sheets are in good condition to make the run.

"THIRD. *Don't* fill the boiler full of water as soon as you get out of the house. Leave a space so the injector can be worked to prevent popping while air pump exhaust is fanning the fire, pumping air to make the terminal air brake test. If you do this your fire will be in better condition to pull out with. The noise of open pop prevents trainmen from locating leaks.

"*Don't* forget to start the lubricator a few minutes before leaving a terminal. Set it to feed regularly. The proper lubrication of valves and cylinders saves coal.

"FOURTH. *Don't* forget, when starting trains, to do so carefully, thus preventing damage to drawbars and draft rigging. By so doing you will save serious delays

*Robt. Quayle.

to your own as well as other trains. All delays mean extra fuel consumption to make up time lost.

"*Don't* neglect using the blow-off cock, as it keeps the boiler clean and water in good condition, and insures better circulation in boiler. Result: Better steaming engine and a saving in coal.

"FIFTH. *Don't* allow the engine to slip. This is an unnecessary waste of coal, wears out tires and rails, causes great damage to pins, axles and running gear, and generally results in spoiling a fire.

"SIXTH. *Don't* pull out of a station with a train (after engine has stood for a while, and fire was allowed to get low) without first giving the fireman a chance to build up the fire. The time lost waiting to do this will save coal, and can better be made up before reaching the next station. Remember this when you get a time order.

"SEVENTH. *Don't* leave the reverse lever down in corner longer than necessary when pulling out of stations. No rule can be made to govern how the throttle and reverse lever should be used. This must be acquired by practice and observing the performance of the engine. Bring the lever up gradually as speed is acquired. The lever hooked well towards center of quadrant, with throttle well open, usually gives better results than using the throttle to govern the speed. Up to five years ago we considered it good practice with our smaller power to run with wide open throttle, and as short a point of cut-off as possible consistent with weight of train; but in our heavier and larger engines we find that it is better at many times to throttle the engine. Particular attention is called to all wide firebox types of locomotives. The engineer can permit the reverse lever in these engines to

remain low in the quadrant when starting from a station for a greater length of time than with the other types of locomotives without pulling the fire or losing steam. When you are running on short time, it would be good judgment for the engineer to take advantage of this when pulling out from a station. In this engineers will use their best judgment.

"EIGHTH. *Don't* put four or five or more shovelfuls of coal into the fire at once. One or two shovelfuls will give better results, and these two should not be thrown in the same spot. It is good practice to fire on one side of the box at one time, and the next time on the other side of the box, in order that the bright fire on one side may take up the gases from the fresh coal on the other side. This will reduce the smoke and give more steam.

"Always fire as light as possible consistent with your work. Very heavy firing will make your flues and staybolts leak, and in time will crack your firebox sheets. The reason for this is that when you have a very heavy fire the air will not pass up through it readily, and the gases pass off, because there is not sufficient oxygen to unite with them to produce combustion, and as the gases must get air from somewhere, the air is then pulled through the fire-door, causing the chilling of flues and sheets as referred to above.

"NINTH. *Don't* allow steam to escape at pops unnecessarily. Frequent blowing off at pops shows improper judgment, and implies that the engine crew is not practicing economy. Tests have demonstrated that ¼ lb. per second, or 15 lbs. per minute, is wasted. This amounts to about one ordinary scoopful, and in most cases may as well have been thrown on the ground as into the firebox. There are only 133 scoopfuls in a ton

of coal, so you can see that you would only have to have your pops open one hundred and thirty-three minutes in the whole day in order to throw a ton of coal away.

"TENTH. *Don't* open the firebox door to prevent steam blowing off at pops when engine is working; dropping dampers is a better practice. The supply of air is cut off, and combustion is partially suspended. When engine stops blowing off, open dampers again before putting in coal. This method keeps fire in better condition and saves coal. You have no doubt noticed that on a certain class of locomotives, when working hard on a hill, you have to shut your dampers in order to keep your fire from turning over. This is because the exhaust pulls too much air up through the grates, and causes your coal to be too active, and to prevent this activity of coal, as well as increased combustion which follows, we consider it a good thing to drop your dampers, as per above.

"ELEVENTH. *Don't* insist upon having the maximum steam pressure with pops opening occasionally when handling light trains, when less pressure will handle the train on time, thus avoiding the opening of pops.

"TWELFTH. *Don't* forget, when engine is shut off for stations, to drop your dampers, opening the firebox door slightly, if necessary, and using the blower to carry off the black smoke.

"THIRTEENTH. *Don't* blame the engine or coal if engine is not steaming properly, before you have ascertained whether or not both of you are doing your duty. Talk it over; see if injector is not supplying more water than is being used, or that fireman is not firing too light or too heavy. Heavy firing is responsible for more poor steaming engines than the lighter method. You all know

some engine crews have better success than others, with same engines and conditions. Think a little; there must be some cause for this.

"*Don't* wait until you get the signal to pull out before building up the fire. This should be done gradually until the proper thickness has been reached. A good fire to start with is essential to maintain the proper steam pressure, while engine is working hard getting train under way. Afterwards distribute the coal evenly on sides, ends and corners. Do this systematically, keeping in mind where you have placed the last shovelful, thus avoiding getting holes in fire, and prevent piling up coal all in one place. Endeavor to keep the steam pressure uniform, with as little black smoke as possible. Experience has taught that engines with draft appliances properly adjusted require very little coal in center of firebox.

"FOURTEENTH. *Don't* permit the water to get so high in boiler that it is carried over into the valves and cylinders. This usually occurs when pulling out of stations, and the water carries off the oil, which not only results in cut valves and cylinders, but the extra friction damages the entire valve motion, to the detriment of the power of engine and the coal record.

"*Don't* gauge the amount of water an engine will safely carry by water coming out of stack. Keep it low enough to insure dry steam being used, because moist steam has the same effect as water. Usually one-half glass or two gauges give best results. Be careful, however, when ascending a grade, and you are about to pitch over the other side, that you have sufficient water to keep your crown-sheet thoroughly covered. If your custom has been to carry high water, try less and

note results in better handling of tonnage, also saving in coal and oil.

"FIFTEENTH. *Don't* neglect to take advantage of your excess steam before your engine is about to pop off, by making a heater of your injector, blowing steam back into the tank to warm the cold water, but avoid getting it so hot that the injector will not lift the water. By doing this you will keep your engine from blowing off at pops when standing at stations after the boiler is filled up. You have all tried warming the water in the tank to help a poor steaming engine, with good results. What is good for a poor steaming engine will surely help a good steaming engine do better. Try it and you will find that it will not only save work for the fireman, but will make a better coal record for the engine crew, besides keeping the tank from sweating, which you are aware spoils paint.

"SIXTEENTH. *Don't* think the fireman alone to blame for your coal record. The best and most economical fireman cannot make a showing with an engineer who supplies more water to boiler than is being used, and who shuts injector off only when boiler is pumped full. The proper handling of the injector is one of the most important matters in saving coal. Feed water to boiler according to demands. If on through train keep water level as possible. If on way freight or switch trains, lose a little water between stations. Fill up again while drifting into, standing or switching at station. The advantages of supplying less water than is being used between stations are: It requires less coal to keep up steam pressure when running; also leaves a space so injector can be worked to avoid pops opening, and heavier fire can also be maintained to do switching, without the possibility of the fire being pulled.

"*Don't* pull out after making a stop with injectors working. The cool water introduced during period throttle was shut off is put in circulation throughout the boiler, and pointer on gauge drops back from five to twenty-five pounds. The fireman must then fire heavier to regain the lost steam, and naturally will use more coal. This condition exists also when engine has gone down grade with throttle shut or slightly open. Shut the injector off before opening the throttle. If this is not your practice, try it and note the difference.

"SEVENTEENTH. *Don't* wait for the pops to open and use this as a signal to put on the injector. Keep an eye on the air gauge, steam gauge and water glass. You all know this can be done without distracting your attention from the track ahead. A look for an instant every mile or two will keep you informed, and is a good habit. Doing this will also keep you posted on air pressure, and may avoid difficulties should the air pump stop. The fireman should also keep an eye on the water glass, as the engineer is sometimes compelled to keep the injector at work to prevent the engine blowing off. When glass is full, the fireman should fire lighter, to give the engineer a chance to shut off the injector, and not have engine blow off. However, this condition should only exist when injector cannot be worked fine enough to just supply amount used. This sometimes occurs when card time is slow, or on down grade, or when running with light train.

"EIGHTEENTH. *Don't* put too much coal under the arch of engines with sloping fireboxes, because these engines naturally pull the coal ahead, which results in forward section of grates becoming stuck and clinkered over, and fire is pulled in back end of firebox. Experi-

ence and observation will teach you to put most of the coal in back end of firebox.

"NINETEENTH. *Don't* think engine having two firebox doors requires twice the quantity of coal it would if engine had but one. The extra door is for the purpose of distributing the coal more evenly over the grate surface, with less effort on the part of the fireman.

"TWENTIETH. *Don't* shovel large chunks of coal into firebox, because you find them on the tank. The coal house men have instructions to break it the size of an apple. If not properly broken, report it to Road Foreman of Engines or to Master Mechanic, instead of fellow engineers or firemen, but don't think it a hardship to break some occasionally. Better break it than to throw in large chunks. They are foundations for clinkers.

"TWENTY-FIRST. *Don't* expect the fireman to fire the engine with one or two scoops to each fire, and also ring the bell for highway crossings and stations. Some engineers expect this. If engine is equipped with an air bell-ringer, get into the habit of starting the bell-ringer when blowing the whistle. By so doing, the habit will become as fixed as whistling for crossings and stations. Besides, it is just as important. Remember the engineer is responsible.

"TWENTY-SECOND. *Don't* put in a heavy fire about the time the engine is shut off for a station or downgrade. The heavy cloud of black smoke is evidence the engine crew is not working in harmony or practicing economy. If on train that stops at all stations, the fireman should guard against it and learn when to stop firing. He will be governed by grade, service and weather conditions. If train does not make all station stops, the engineer should keep the fireman informed of intended stops.

"TWENTY-THIRD. *Don't* forget that different qualities of coal and different make of grate used, govern the shaking of grates. Coal that fills up and clinkers, requires more attention than the better grade. The object is to keep the grates free, so the proper amount of air can be admitted.

"TWENTY-FOURTH. *Don't* neglect cleaning your fire on trains that are long hours on the road. Make use of the first opportunity. You will get better results with less labor and coal, and avoid leaky flues. Better clean out a small amount two or three times than not clean it at all.

"*Don't* take coal or water oftener than necessary, as it requires an extra amount of coal to again get a heavy train in motion, especially on a grade. Good judgment is required in order not to run short before getting to next coal chute or water tank. Where possible take water only from tank containing good water, and as little as you can from tanks containing poor water.

"TWENTY-FIFTH. *Don't* forget that leaks in the air pressure are being kept up by an equal amount of steam pressure. As it takes coal to make steam, air leakage means a waste of coal. Keep apparatus on your engine tight, and insist on trainmen doing their part.

"TWENTY-SIXTH. *Don't* try to put more coal on tank than will die on it securely. All coal dropped off by overloading is wasted. Also keep coal from falling out of gangway when running. This may be only a little each day, but it all counts against your coal records; besides it looks badly when strewn along the tracks. You can not save coal by the ton; it must be in pounds, which in time make tons.

"TWENTY-SEVENTH. *Don't* forget to make an intelligent report on your work slip on arrival at Round house

Consult your fireman in regard to any defect that has come to his notice, especially with grates, dampers or firing tools.

"TWENTY-EIGHTH. *Don't* neglect reporting the pop valves ground in when leaking or when they blow back eight or ten pounds before seating. Also report leaky piston rod and valve stem packings, or if cylinder packing or valves are blowing. All these leaks draw on the coal pile unnecessarily; it takes coal to generate the wasted steam. This also applies to leaky steam heat appliances, cylinder cocks, etc.

"TWENTY-NINTH. *Don't* neglect looking at coal report each month to see how you stand in relation to others in same service with whom you are comparable. The other crews get the same pay you do, and it should be your aim to be as economical with both fuel and supplies as they are, other things being equal. Keep posted and be with the average. It will be to your credit and interest some time; therefore aim to be at the top.

"THIRTIETH. *Don't* think when coal report shows you using only two pounds more per 100 ton mile than other crews in same service, it is close enough. This means two pounds more used for every mile you hauled 100 tons—or another way, two pounds for every 100 tons hauled one mile. Figure this up and you will find in hauling 1,000 tons 100 miles, a difference of 2,000 pounds or one ton. This method of showing up the individual record is more equitable to all than on basis of mile run per ton of coal.

"THIRTY-FIRST. *Don't* think, after reading over this chapter of *"Don'ts"* you should save coal to the detriment of the service. The actual amount required to make up time, keep on time, or handle tonnage, is not what we are trying to save; it is the waste."

CATECHISM ON BREAK-DOWNS.

Question 1.—If an engine pounded when steam was shut off, what would it indicate?

Answer 1.—Flat drivers, loose follower bolt, main rod too short or too long.

Question 2.—What would you do in case of a broken trailer equalizer?

Answer 2.—Raise the back end of the engine and pry down the back end of main spring and block between hanger and frame; then pull down the cross equalizer on that side and block between the top of trailer, the equalizer and the frame to hold it there.

Question 3.—How would you block up for broken trailer tire?

Answer 3.—Run the trailer wheel up on a wedge a little higher than the thickness of tire, remove cover from trailer box, takeout cellar and place a block between bottom of journal and the box, place a block between bottom of box and pedestal and block cross the equalizer up in safety hanger, or chain it to frame, place a tie or rail over deck of engine and chain trailer frame to tie, by the use of wedges the slack can be taken up in the chain.

Question 4.—How would you proceed to block up for a broken driver spring, spring hanger or equalizer on the Atlantic type (4-4-2 class) of engine? How for a broken trailer or hanger?

Answer 4.—For main spring, run main driver up on a wedge, block up back end of front equalizer and block

back end of back equalizer, run main driver down and run the front driver up, and put a block between the top of main driving box and the bottom of frame. If front driving spring, run main driver on wedge high enough to block between top of front driving box and bottom of frame, run main wheel down and front wheel up, this will free the spring rigging and permit blocking between front end of forward equalizer and top of bottom frame. For trailer spring, raise frame and cross equalizer by placing a block between a tie and the bottom frame, and another block between the end of cross equalizer and tie, move engine on these blocks very carefully, put tie across top of trailer box in place of spring and chain back end of tie to trailer frame, and front end to cross equalizer. For front trailer spring hanger, chain across equalizer to end of spring. If back hanger, block between water leg of fire-box and spring, raise engine up same as for broken spring.

Question 5.—What would you do in case of a loose or a lost cylinder key?

Answer 5.—Replace it with a suitable piece of iron, such as rod key, spike, etc.

Question 6.—Name the different parts of the engine that operate and control the valve motion.

Answer 6.—Reverse lever, reach rod, reversing arm, tumbling shaft, lifting arms, link hanger, link saddle pin and link, link block, link block pin, eccentrics, eccentric blade, rocker arms, valve rod and stem, valve yoke and valve.

Question 7.—How often does the ordinary locomotive exhaust steam during a revolution of the driving wheels, and at what point does the exhaust take place?

Answer 7.—The ordinary locomotive has four ex-

hausts. When the right hand crosshead has moved back from the forward center to nearly the middle of the guides, the left engine is exhausting on its forward stroke. When the right hand crosshead reaches close to back end of guides, the right engine is exhausting on its backward stroke. When the crosshead returning reaches near the middle of the guides, the left engine is exhausting on backward stroke, and when the crosshead reaches close to the forward end of the guides, the right hand engine exhausts on the forward stroke.

Question 8.—What is a by-pass valve, and what are its uses?

Answer 8.—The by-pass valve is a small valve similar to the check valve located on each end of the steam chest for the purpose of overcoming excessive compression. It is connected with the live steam side of the valve, and the steam port between the valve and the cylinder. It is held on its seat by boiler pressure and unseated when the compression in the cylinder is greater than the boiler pressure.

Question 9.—If a by-pass valve was broken, how would you test for it?

Answer 9.—A broken by-pass valve will cause a heavy blow at the stack when the exhaust port is open. Cover the exhaust port with the valve and if the blow ceases it indicates a by-pass valve blow.

Question 10.—What is a balance slide valve?

Answer 10.—It is a valve from which the steam-chest pressure is withheld from part of the top of valve.

Question 11.—How is it balanced and why?

Answer 11.—The types of valves are the Richardson, American and the piston valve. There is a face plate on the bottom side of the steam chest cover to both the

American and Richardson valves, parallel with the top of valve and about 1-16 inch above it. The lower face planed smooth. The top edges of the Richardson balance valve have grooves in which the packing strips are set and are held up against the balance plate by springs. The difference between the American and the Richardson valves is in the balance. In the American valve, beveled rings are used instead of strips. The rings, which are made circular in form, have their inner face beveled to suit the bevel of the cone on top of the valve in which each ring is placed, and each ring is cut to make it flexible. The rings are turned up slightly smaller than the cone upon which they set, so, when they are forced to position by the steam chest cover, they are expended slightly by the beveled face of the cone. When the steam is admitted to the chest it exerts a force on the entire outside face of the ring. This causes the ring to press more firmly against the cone and balance plate, which makes a steam tight joint. Piston valves are balanced by steam, it being nearly equal on all sides. Valves are balanced for the purpose of reducing friction between the rubbing surfaces.

Question 12.—What is the hole drilled in the top of the valve for?

Answer 12.—The hole drilled through the top of the valve into the exhaust cavity is for the purpose of relieving the top of the valve of any steam that might pass the packing rings or strips.

Question 13.—In the event of a valve, valve stem or yoke becoming broken inside the steam chest, how can the breakage be located?

Answer 13.—Place engine at half stroke, admit a little steam to cylinder; then move the reverse lever from full

forward to full back gear, and if steam will escape alternately from both cylinder cocks, would conclude that the defects were in the opposite chest and then try that side.

Question 14.—After having determined on which side the defect is, how would you put the engine in safe condition?

Answer 14.—For broken valve, if I could cover one admission port and exhaust port, would disconnect the valve stem and clamp centrally on seat. Disconnect the main rod and block the crosshead to opposite end of guides. If exhaust and admission ports cannot be covered, take up the chest cover and block the supply ports. If on heavy power, take down the main rod and prepare to be towed in, as some of the pieces might work into the cylinder and do further damage.

Question 15.—If on a piston valve engine?

Answer 15.—If stem or yoke is broken, and chest will keep valve from going too far ahead, it will cover front admission port and exhaust port; disconnect valve stem and shove it up against valve and clamp it there, take down main rod, block crosshead to opposite end of guides to which admission port is open. If valve goes too far ahead, and there is a relief valve in front of the chest, take it out and shove the valve back centrally on its seat; fit a block in, to hold from going ahead, and clamp the stem up against it to keep it from going back. If piston valve, take off head to chest, and if the valve is not broken too badly, place it centrally on its seat, and block from the head to the valve to keep it from going ahead; disconnect the valve stem and clamp it against the valve to keep it from going back. If the valve is broken so badly that you cannot keep steam from the

exhaust, take down the main rod and prepare to be towed in. If stem on piston valve, plumb the rocker arm and disconnect valve stem and clamp it, then shove valve back against the stem and block between valve and head.

Question 16.—If a locomotive is disabled on one side, and the main rod and the piston are left up, and the good engine stops on center, how can you get the locomotive started?

Answer 16.—Move the valve on the disabled side by hand, giving the engine enough steam to move her off center.

Question 17.—How can you distinguish between a valve, cylinder packing, or valve strip blow; and how locate which side it is on?

Answer 17.—A valve blow is continuous, cylinder packing will blow the hardest at the beginning of the stroke. Place valve centrally on its seat, giving engine steam, and if it appears at either cylinder cock, it is a valve blow. For cylinder packing blow, place lever in full gear, engine on the quarter and give engine steam; if it appears at the opposite cylinder cock, it indicates cylinder packing blow. A valve strip is a continuous blow, sounding as though the blower was on quite strong. The side it is on can be located on engines that have pipes or drain cocks tapped onto the exhaust cavity under the saddle by giving engine a little steam when standing, and steam will blow out of pipe on whichever side the leak is. This kind of blow can also be located by the increased friction, which will cause the valve stem on that side to jerk when in motion; or it may be located by placing the crank pins on the quarter alternately and handling the reverse lever under steam pressure; the blow will be on the side which handles the hardest.

Question 18.—What would you do if the packing blew out of the throttle stuffing box?

Answer 18.—Reduce steam pressure and repack the stuffing box with candle wicking, bell cord, or anything suitable to stop the flow of steam and water.

Question 19.—Explain why moving the reverse lever from one end of the quadrant to the other reverses the motion of the engine.

Answer 19.—With the reverse lever in forward gear, the link is below the center line of motion and the go-ahead eccentric controls it; with the lever in back gear the link is raised above the center line of motion and the back-up eccentric controls it.

Question 20.—What is the throw of an eccentric?

Answer 20.—That part which is out of center with the axle to which it is attached.

Question 21.—With an engine equipped with grease in the driving box cellars, how would you know that there was sufficient grease in the cellar to make the trip? If it needed packing on the road, how would you proceed to pack it?

Answer 21.—By the indicators in the bottom of the cellar. By pulling down on the indicators which compresses the spring, remove plate on side of the cellar and refill with grease, being careful to get it between the perforated plates and the plate on top of spring.

Question 22.—Explain how you would adjust the grease cups to get the best results, and effect the greatest economy in the use of grease.

Answer 22.—Grease cups should be filled to within one-half inch of the top; care should be exercised in screwing down the plug not to force too much grease onto the pin. A good practice is to first try the rod on the

pin; if it moves freely screw the plug down until you feel the rod commence to move hard; you then have sufficient grease on the pin to run over the division.

Question 23.—In reporting work on any wheel or truck of engine or tank, how should you designate by number which one is meant?

Answer 23.—Beginning with the first wheel behind the pilot as No. 1 and following to the rear wheel of tank, not including the drivers, designate them in their numerical order and using the letters "R" and "L" to indicate the side of engine on which they are.

Question 24.—What would be the result if guides and crossheads are not in line?

Answer 24.—Danger of guides heating and cutting, also breaking off of guide lugs on back cylinder heads, cylinder wearing out of round and main rod brasses heating.

Question 25.—Why should the sand from both sand pipes strike the rail?

Answer 25.—To avoid straining the engine on one side more than on the other and to prevent uneven wear of tires.

Question 26.—What is superheated steam?

Answer 26.—Superheated steam is steam heated to a higher temperature than the water from which it is generated.

Question 27.—How is it superheated and what benefits are derived from it?

Answer 27.—It is superheated by passing through a system of tubes which are exposed to the fire and the hot gases in the front end and give it more expansive power.

Question 28.—How is the boiler of the locomotive connected to the frames?

Answer 28.—The front end of the boiler and the frames are securely fastened to the cylinder saddles, again about midway back, the boiler is secured to the frames by belly braces to prevent side motion but not expansion, and at the fire-box side motion is also prevented. The fire-box end of the boiler is carried on the frames by expansion plates or by expansion hangers, as the case may be, but is free to move backward and forward on the frames as expansion and contraction take place. If the frames were as hot under steam pressure as is the boiler, the fire-box end of the boiler could be rigidly attached to the frames.

Question 29.—With an ordinary sized locomotive boiler how much will the fire-box move on the frames?

Answer 29.—About three-eighths to one-half of an inch.

Question 30.—Are the cylinders fastened rigidly to the frames?

Answer 30.—Yes; in fact they are generally a part of the saddle castings.

Question 31.—Are the driving wheel axles secured rigidly to the frames?

Answer 31.—No; the driving boxes riding these axles can move up and down to permit the wheels to conform to the inequalities of the track but are rigidly held against forward and back motion by shoes and wedges bearing against the jaws of the frames.

Question 32.—Are the frames supported directly by the driving boxes?

Answer 32.—No; the driving boxes support springs, the ends of which are fastened to the frames directly or through equalizers.

Question 33.—What is the purpose of the equalizers?

Answer 33.—To always retain same weight upon each driving box, even when one wheel strikes a high or low spot in the track. They make an engine ride more easily on rough track.

Question 34.—How hot should you have engine oil to oil around with in winter?

Answer 34.—No hotter than blood heat—98 degrees—and if oil is then too thick to run well, thin it down with kerosene.

Question 35.—What is the harm of thinning it by heating it very hot?

Answer 35.—As soon as it strikes the cold surfaces it will thicken and not feed properly to the bearings.

Question 36.—When wedge bolts are broken so that you have to slip in an extra nut between the wedge and the binder, or splice the bolt by running half of the nut on each side, should the wedge be set up tight?

Answer 36.—It should be left down a trifle, for it is better to have the box pound a little than to run the risk of having the wedge stick on the box and get pulled up and stick fast with no means of pulling it down.

Question 37.—What trouble is likely with broken wedge bolts?

Answer 37.—Wedge is likely to stick to the box on rough track and be pulled up so high as to stick and cause the box to run hot.

Question 38.—What would be the effect of broken cylinder packing?

Answer 38.—Steam when admitted to one end of the cylinder would blow by the piston and show at the other end of the cylinder, if the cylinder cocks are opened.

Question 39.—What is meant by "snap-ring" packing?

Answer 39.—A circular ring usually of cast iron and

cut at one point. This ring is opened up and snapped over a solid piston or applied each side of the bullring in a made-up piston. Such rings are made from one-eighth to one-fourth of an inch larger outside diameter than the cylinder and a piece cut out so that the ends will just touch when compressed in the cylinder.

Question 40.—When such rings are first applied to a cylinder why do they often permit steam to blow by for a short time?

Answer 40.—Because they generally have to wear slightly before they conform perfectly to the shape of the cylinder.

Question 41.—If a ring becomes worn until it has a smaller outside diameter than that of the cylinder what will be the result?

Answer 41.—It will allow steam to blow by the piston, but not always at high steam pressures. The engine will be wasteful of steam, and yet if tried under high steam pressure may set the packing out sufficiently to prevent a blow. With such an engine under short cut-off, when the steam had expanded somewhat in the cylinder the pressure would not hold the packing rings in place and steam would blow by. Test such an engine under low steam pressure.

Question 42.—What would be the "symptoms" in the above case?

Answer 42.—The engine may have made several thousand miles since shopping and used steam economically and then lose her "snap" and apparently through at early cut-off and high speed. By dropping the lever, thus increasing the pressure behind the snap rings during the entire stroke, the blow ceases.

Question 43.—What will be the result if brasses are not kept keyed up properly?

Answer 43.—They will wear rapidly and often break themselves. Any serious pound about a locomotive is liable to loosen various parts of the engine.

Question 44.—Is it safe to key up side rods with the wedges down or loose?

Answer 44.—It is not; the wedges should be first set up or you are likely to key the rods out of tram.

Question 45.—Would you set up wedges as tight on a passenger engine as on a freight engine?

Answer 45.—No; on a passenger engine most men prefer to set them up a little at a time.

Question 46.—Would the condition of the track make any difference?

Answer 46.—Yes, on rough track wedges are more likely to stick if set up tight.

Question 47.—What will be the result if an engine is out of tram?

Answer 47.—She will ride hard, having a hitch every time the rods pass the center, the pins are likely to heat and considerable of the engine's power be wasted.

Question 48.—If you felt a pound after keying up the main rod what is likely the cause?

Answer 48.—Probably the main rod is too long and allows the piston to strike the front cylinder head. Such a pound is most noticeable when steam is shut off and the engine drifting as there is then less compression to counteract this.

Question 49.—How could you shorten a main rod?

Answer 49.—By changing a thin liner from the end of the rod to the back of the strap. Such work is usually done at roundhouses by the machinists and repairmen.

Question 50.—Will a loose pedestal brace or bolt cause an engine to pound?

Answer 50.—It will, and if not attended to is likely to break the frame.

Question 51.—With a follower bolt loose, what will be the effect?

Answer 51.—It will cause a pound at the forward end of the stroke when it strikes the front cylinder head. Shutting off steam, as in the case of too long a main rod, will increase the pound.

Question 52.—Is it safe to run with a loose follower bolt?

Answer 52.—It is not, as it is likely to come out, knock out the front cylinder head, and perhaps break the piston and cylinder. Work a little steam and try to get to the next siding if the pound does not increase and there take off the cylinder head and remove the bolt, unless you have a good wrench with which to tighten it.

Question 53.—If for any reason you should have occasion to open the front end door, how would you proceed to tighten up the clamps?

Answer 53.—Close the door, tighten the bottom clamp first, then the clamps on either side; the top one last, so that if the door or ring is warped any leakage will be at the top of door, and though injurious in a degree to the draft of the engine, still it will not cause the cinders in the front end to burn.

Question 54.—What is wrong when the throttle becomes disconnected, and what could you do if on a branch line a long distance from the shops?

Answer 54.—One of the pins has probably come out of or broken from the bell crank or the stem, or the throttle valve rod is broken. Blow all the steam off the boil

take up dome cap, discover the defects, send it in for repairs or better still fix it yourself at the nearest blacksmith shop. In early days of railroads in this country, enginemen frequently did such extensive repairs as this themselves.

Question 55.—Will any defects in the front end cause an engine to sound out of square?

Answer 55.—Yes; exhaust pipe joint blown out on one side or one tip of a double nozzle blown out. Sometimes a wornout petticoat will also cause this.

Question 56.—What term is used where an engine has no lead?

Answer 56.—The engine is called "blind."

Question 57.—What will be the effect if the eccentric has slipped toward the crank pin on that side?

Answer 57.—The amount of lead will be increased, and hence steam admitted to the cylinder considerably before the piston gets to the end of its stroke.

Question 58.—What will be the effect if the eccentric has slipped away from the crank pin on that side?

Answer 58.—The lead will be taken away, and if slipped much, the piston may have started on its return stroke before steam is admitted.

Question 59.—How can you tell which is the go-ahead and which is the back-up eccentric?

Answer 59.—The go-ahead eccentric is attached to the top of the link, the back-up to the bottom, on all ordinary locomotives.

Question 60.—What other aid have you to find a slipped eccentric or rod after you have stopped?

Answer 60.—If I found one eccentric hot or the set screws loose, would consider that first.

Question 61.—If only one eccentric has slipped, how

can you tell what its position should be in reference to the other eccentric?

Answer 61.—The go-ahead eccentric on one side should be exactly ninety degrees or at right angle to the other go-ahead eccentric, and the relative position of the back-up eccentric is the same. Whichever crank pin of the engine leads, the eccentric on that side leads the opposite one. This answer is true for all kinds of valve motion.

Question 62.—How can you set an eccentric on the road by means other than its relative position to the other, or to the crank pin?

Answer 62.—Place the engine on either center on the defective side. Put the lever in full gear for the good eccentric and with a knife mark the valve stem close to the gland. Now place the lever in equally full gear (gauging by the link block) in the opposite direction, and then move the loose eccentric around on the shaft until the strap on the valve stem comes even with the gland again. Another way is to put the engine on center on that side, put the reverse lever in full gear for that motion, set the brake and block wheels securely; have the fireman open the throttle slightly while you move the slipped eccentric in the opposite direction from the one next to it until steam shows at the cylinder cocks at the end of the cylinder wherein the piston lies.

Question 63.—Why are slipped eccentrics of less occurrence now than in former years?

Answer 63.—Now they are almost all keyed on, the set screws only keeping them from sliding endwise on the axle; formerly the set screws were depended upon entirely to hold them in place.

Question 64.—On which center would you place an engine to set an eccentric?

Answer 64.—On whichever center enabled me to more easily get at the eccentric and set screw.

Question 65.—In case of a very hot eccentric, would you put water on it?

Answer 65.—You should not, as it would be likely to break or warp the strap.

Question 66.—What usually causes the eccentrics or blades to slip?

Answer 66.—It may be any of several causes: set screws loose, hot eccentrics or someone tightening up set screws when the bolts holding the two eccentric parts together are loose. In this latter case the cam would be jacked out tight against the strap.

Question 67.—What would you do for a hot eccentric on the road?

Answer 67.—Oil it well, using valve oil if very hot; see that the strap was not tight on the cam and if it were, loosen the strap bolts and put in one or more tin liners between the two halves of the strap on both sides, then tighten bolts.

Question 68.—How do some roads secure blades in straps so as to prevent their slipping?

Answer 68.—Some roads slot all holes and after the blades are set and adjusted, they run soft metal into the slots beside each bolt. Other roads often slot one hole in each blade and after setting valves drill the remaining holes to correspond with those in the strap without slotting them.

Question 69.—What would you do to "disconnect" an engine on one side, as the term is generally applied?

Answer 69.—Place the valve in the center to cover the

steam ports and clamp or bind the stem to hold it there, take down the main rod and block the crosshead securely (preferably at the back end of stroke). If any side rods are broken, remove the same ones on the opposite side.

Question 70.—On very heavy locomotives is there any way to avoid taking down the main rod?

Answer 70.—Yes; if but a short distance to go, block the valve just enough ahead of the center to admit a little steam to the back end of the cylinder, and if the engine does not have by-pass valves take out the back cylinder cock or block it open and loosen the front cylinder head.

Question 71.—For what causes would you disconnect as stated?

Answer 71.—For broken front cylinder head; valve, valve seat, valve stem or rod broken; broken rocker arm, eccentric, strap, blade, link or parts of link.

Question 72.—If you take down one eccentric blade, what should you do to prevent the link turning over, binding, or striking the engine truck frame?

Answer 72.—Tie the top of the link to the hanger or otherwise fasten it, but not too tightly. It is generally better to take off both eccentrics and straps on that side if you have to take down one.

Question 73.—Can an engine be run ahead with a back-up eccentric strap or blade taken down?

Answer 73.—Yes; for if kept in full gear the link block will get all its motion from the go-ahead blade. The reverse condition is true with regard to a broken go-ahead eccentric. This practice should not be followed except in moving an engine to the nearest siding before disconnecting the valve stem.

Question 74.—What would you do if the whistle or pop valve should blow out?

Answer 74.—Plug the opening with a piece of soft wood and tie it down if possible.

Question 75.—If stuck in a snow bank, how would you keep water in the tank?

Answer 75.—If necessary, shovel snow in the tank and melt it with the heater.

Question 76.—When an engine is standing and the throttle is closed, what will cause steam to escape from the cylinder cocks?

Answer 76.—If the lubricator was shut off so that no steam could come through the oil pipes, it would indicate either a leaky throttle or a leaky dry pipe.

Question 77.—How can you distinguish a leaky dry pipe from a leaky throttle valve?

Answer 77.—With a dry pipe leaking, if there is enough water in the boiler to cover it, the escape from the cylinder cocks will be nearly all water. With the throttle leaking it will show dry steam.

Question 78.—Is a leaky throttle dangerous?

Answer 78.—It is, and should be reported and ground in as soon as possible; in the meantime leave the cylinder cocks open when standing and block the wheels well before going under the engine or leaving her.

Question 79.—Then to test a leaky dry pipe should there be more water than usual in the boiler?

Answer 79.—Yes; some boilers have to be filled above the top of the water glass in order to entirely submerge the dry pipe should the latter leak at its top side.

Question 80.—Name the various causes for an engine pounding.

Answer 80.—Loose or worn rod brasses or worn pins; loose or worn wedges or binders; driving box brasses worn or loose in the boxes; piston rod loose in its crosshead; worn guides or crosshead; loose gibs in crosshead; loose cylinders or deck; flat driving wheels; main rod too short or too long or loose follower bolts; badly worn expansion pads on the sides of the fire-box; a broken frame; pedestal bolts loose.

Question 81.—Name the various causes for a blow in an engine.

Answer 81.—Valves, valve seats or cylinder cut; balance strips broken, stuck down or broken springs under strips; balance plates too high above the valve; broken or worn packing rings in piston valves; broken or worn cylinder packing rings or rings turned around so that their openings come opposite each other at the top of the piston; broken valves or valve seats, and sometimes a blow under a false valve seat.

Question 82.—How would you test for a blow in the balance strips or valves?

Answer 82.—Place the engine on the center (forward preferred), the reverse lever in center notch, and open the throttle and cylinder cocks. If very little steam shows at either cylinder cock on that side, defective balance strip will still cause a blow through the hole in top of valve to the exhaust cavity and out of the stack. By moving the lever a notch or two each side of center, just enough to connect the exhaust cavity with either cylinder port, a slight escape of steam will appear at the corresponding cylinder cock. Test the opposite side of the engine in the same way.

Question 83.—Why are all large valves balanced?

Answer 83.—To reduce the frictional resistance and also the wear between the valves and their seats.

Question 84.—What provision is made for the escape of any steam that may leak to the inside of the balance strips or rings?

Answer 84.—A hole is drilled through the top of the valve into the exhaust cavity.

Question 85.—If this hole were plugged, what would be the effect?

Answer 85.—The valve would be unbalanced and like an ordinary slide valve.

Question 86.—What advantages are claimed for piston valves?

Answer 86.—Greater port areas and more evenly balanced valves.

Question 87.—In what way have some slide valves been given greater port areas without increasing the size of the valve?

Answer 87.—By supplemental ports. The Allen valve being the most common.

Question 88.—What is meant by the valve being "line and line" inside?

Answer 88.—With the valve on the center of its seat, that the inside edges of the cylinder ports are in line with the edges of the exhaust cavity.

Question 89.—What is the advantage of working steam expansively?

Answer 89.—To effect an economy of steam which means economy of fuel. The following tables from a well known authority will clearly indicate the reasons for this economy if the student will compare the total heat with the amount of work done in each case:

Cut-off, Inches.	Initial Steam Pressure.	Ratio of Expansion.	Average Cylinder Pressure for Entire Stroke.	Ft.—Lbs. Work done.	Heat contained in steam used.	Pounds of water used in doing the work.
8	200	3	125	31,800	618	.52
24	140	1	125	31,800	1299	1.12

EXPLANATION.—The above table shows that 200 pounds of steam with a cut-off of 8 inches (one-third stroke) gives the same average cylinder pressure for the whole stroke and does the same amount of work but with less than one-half the heat and the water that a full 24 inch stroke with 140 pounds of steam pressure will give.

Pounds of steam used.	Initial Steam Pressure.	Cut-off (with 24-in stroke.)	Ratio of Expansion.	Pressure in Cylinder at end of stroke.	Average Cylinder Pressure for Entire strke.	Ft.—Lbs. Work done.	Total heat at 200 lbs. pressure.	Total heat at final pressure	Heat saved	Comparison of work done.
1.57	200	24	1	200	185	47,064	1833	1833	0	1.00
1.57	200	12	2	100	155	78,864	1833	1807	26	1,67
1.57	200	8	3	66	125	95,400	1833	1793	40	2.02
1.57	200	6	4	50	105	106,848	1833	1775	58	2.27

EXPLANATION.—From the above table the last column shows the relative advantage of the shorter cut-offs over the full stroke—the first line of table.

Question 90.—Cannot economy be effected with cut-offs still shorter than six inches?

Answer 90.—Not with our modern high pressure boilers, for with still greater expansion the final temperature in the cylinder is so low that great condensation takes place in the cylinders.

Question 91.—Is there any other bad result from too short a cut-off?

Answer 91.—Yes; flat spots are made in driving wheel tires by such practice. Some roads go so far as to block quadrants of locomotives so that the reverse lever will not latch anywhere between the center and the six-inch cut-off notch.

Question 92.—What effect has it on the valve to lengthen or to shorten the blades?

Answer 92.—It equalizes the travel with reference to the center of the valve seat but it does not alter the total lap or lead of the valve—whatever amount it takes from one end of the valve is added to other end—that is to say, if the lead is one-sixteenth inch at one end and line and line at the other end, if you lengthen or shorten the eccentric blade (according as the rocker arms are arranged), the lead can be divided so as to be one thirty-second of an inch at each end.

Question 93.—What is the usual cause for cracked or broken steam chests?

Answer 93.—Reversing an engine when throttle is shut off and the engine is running at high speed.

Question 94.—Why is this likely to rupture a steam chest?

Answer 94.—The cylinders of a reversed engine draw air and gases from the front end and force them into the steam chests, steam pipes, dry pipe and stand pipe, and as the throttle is closed there is no escape. The more modern locomotives have steam chest relief valves in order to relieve such excessive pressure.

Question 95.—What should be done if an engine is reversed at high speed?

Answer 95.—Open the throttle which will allow the air to pass into the boiler and be relieved at the safety valves.

Question 96.—If the reverse lever should get caught and bound tightly at a short point of cut-off (due to broken driving spring, spring hanger, or equalizer) what would you do?

Answer 96.—Try to pinch the light engine ahead sufficiently to take steam, then block up for broken parts.

If necessary to get the train off the main track quickly, you can disconnect the reach rod from the tumbling-shaft lever and let the links drop down onto the link blocks so that the engine will be in full forward gear. If you have any distance to go, get the engine blocked for the broken parts, free the reach rod and reconnect the tumbling-shaft arm.

Question 97.—How could an engine be moved if the engine truck was demolished?

Answer 97.—Jack up the front end of engine and block up on top of the forward driving boxes and run very slowly to prevent these forward driving boxes from running hot.

Question 98.—At what points of the frame is the weight of a locomotive carried?

Answer 98.—At the equalizer stands, front and back hangers and at the engine truck center casting.

Question 99.—In blocking the crosshead of a locomotive, subsequent to disconnecting, does it make any difference whether it is blocked ahead or back?

Answer 99.—Yes; with engines having their forward driver opposite the guides the crossheads must be blocked full ahead or the forward crank pin may strike the wrist pin.

Question 100.—In case it becomes necessary to remove the side rods on such an engine can the engine be run safely?

Answer 100.—Not always. It should be definitely determined that the crosshead pin or key and forward crank pin cannot interfere with each other.

Question 101.—In taking off a main rod how are the side rods to be held on the main pin?

Answer 101.—By a wood or iron collar to clamp on the

outer end of pin, thus taking the place of the main rod. If there is no such collar on hand, saw pieces of wood to fit the pin lengthwise and tie them securely around the pin.

Question 102.—With a broken frame jaw, what would you do?

Answer 102.—I would try to take my train in.

Question 103.—If an engine with a broken frame is to be towed, how should it be done?

Answer 103.—Such an engine should not be towed either at the front or rear of a long heavy train as the shocks and strains on the frame are too severe in such a train.

Question 104.—What would you do if the spring of the steam chest relief valve were broken so that the steam blew badly?

Answer 104.—Screw down on the spring, or block the valve closed, and report it at the end of the run.

Question 105.—How does the rod grease cup work?

Answer 105.—By means of a screw plug or piston, the grease in the cup is forced down through the small oil hole onto the pin.

Question 106.—If you put water on a pin using grease what is the result?

Answer 106.—It forms soap of the grease and causes it to rapidly disappear from the cup.

Question 107.—How would you try to get a leaky or stuck open boiler check to close?

Answer 107.—Tap it gently on the flange of check, open the "frost" cock and pour cold water over check.

Question 108.—What usual precautions must be taken in cold weather?

Answer 108.—Trains must be started and stopped very

carefully to prevent breaking of draft gear or sliding wheels. If any water or steam is leaking from the tank, be sure the wheels are turning when you start as a brake shoe is very likely to freeze to the wheels and slide them.

Question 109.—Where is the frost cock?

Answer 109.—It is located on the discharge or "branch" pipes on either side and at the lowest point, usually a few feet from the boiler check and nearly above the guides.

Question 110.—What damage can water do if it escapes from these frost cocks?

Answer 110.—It may freeze on the guides and blow all over the links, eccentrics and running gear of the engine; hence a pipe should lead from these cocks to a point near the ground and this pipe always be seen to be open and not frozen up.

Question 111.—What would result from a too free use of the heater?

Answer 111.—The feed water in the tank would become too hot to be taken up by the injector and cause trouble from failure of the injectors.

Question 112.—What else should be watched in cold weather?

Answer 112.—The air pump, steam bellringer, and electric headlight engine (if you have one). Do not allow any of them to be shut off for any considerable length of time, but keep a little steam flowing through them even though their services are not required. Before taking an engine out of the house in very cold weather, go to the back end of the tank and blow out the rear air brake, air signal, and steam heat hose to be sure they are open, as these are near the roundhouse doors, and sometimes freeze up.

Question 113.—In cold weather why are leaks in the mud ring much worse than at other times?

Answer 113.—Because this water will soon freeze up the ash pan and the dampers, and shut off all draft. A steam hose with a connection to the syphon cock on top of the dome is carried on many engines in very cold climates. With this hose ice and snow may be melted from the machinery, ash pan and dampers, when necessary.

Question 114.—At what time of year do the most hot boxes occur?

Answer 114.—During the coldest portion of the winter.

Question 115.—Why is this?

Answer 115.—Because then lubrication is the poorest, ice and water get on top of driving boxes and prevent oil from feeding, and the waste in cellars gets frozen stiff so it does not bear against the journal. In very cold weather clean off and put new waste on top of the driving boxes frequently.

Question 116.—How are many locomotives equipped for cooling hot bearings?

Answer 116.—By water pipes leading to the cellars of every journal on the engine and also the pins.

Question 117.—When would you turn water onto a hot bearing?

Answer 117.—Only when, to the best of my judgment, a failure to do so would result in serious delay to my train, or other important trains. It is best to endeavor to cool off the bearing by better lubrication, than to use water which washes off the oil.

Question 118.—Why is it thought best to put the water pipes in the cellars instead of on top of the bearings?

Answer 118.—Because it still allows some oil to be fed down from the top, instead of washing it all off.

Question 119.—What kind of waste is best for use on cellar-packed journals, such as engine trucks, tank trucks, trailer wheel boxes, and driving box journals?

Answer 119.—Good long fibre cotton waste, having been saturated in oil for not less than 24 hours.

Question 120.—Why is cotton waste better than wool waste for such purposes?

Answer 120.—Because it has much better capillary attraction and feeds oil up much better.

Question 121.—How can you prove this?

Answer 121.—By suspending a long cotton cloth and a woolen one with their lower ends in water or oil, and then note how much more rapidly the water or oil feeds up the former.

Question 122.—Such being the case, why do so many roads use wool waste in all engine trucks and driving box cellars?

Answer 122.—Because it has more "spring" to it and hence does not pack down and away from the journal so quickly.

Question 123.—What special forms of cotton packing are made with the intent of increasing its spring?

Answer 123.—Various forms of woven and twisted fibre and an ordinary cotton waste with a fine steel shaving running through it to give it spring.

Question 124.—If a tender or engine truck box ran hot in spite of your best efforts, what would you do?

Answer 124.—If I had an extra brass on the engine to fit this, jack up the box and remove the brass. In the case of an engine truck this would cause too long a delay to an important train, hence the use of the water pipe on many locomotives.

Question 125.—If your rod brasses were babbitted and

you noticed a pin getting hot enough to melt the babbitt and was throwing it out, what would you do?

Answer 125.—I would not stop until all babbitt was thrown out and hence the oil hole open. Should I stop at once the babbitt would likely close the hole in the strap and oil cup and cause a great deal of trouble in removing it.

Question 126.—In what does the abuse of an engine consist?

Answer 126.—Not taking proper care of, or reporting the work to be done on an engine, slipping an engine unnecessarily and catching the engine on sand, reversing an engine while moving, working the engine harder than necessary, pulling or tearing holes in the fire, irregular boiler feeding and poor firing.

Question 127.—Should either injector be used to the exclusion of the other?

Answer 127.—No; non-use is one of the most frequent of injector troubles. Many reliable enginemen think it an excellent plan to use, say, the right injector going over the road in one direction and the opposite injector on the return trip.

Question 128.—Why cannot this be made a good rule to follow on all engines?

Answer 128.—Because many locomotives have a size larger injector on one side than on the other.

Question 129.—If an injector is continually used for a heater, what will likely follow?

Answer 129.—The hose strainer gets coated with lime; the boiler check and adjustable parts of injector become covered with scale and stuck.

Question 130.—How many miles should an engine run to the pint of lubricating oil?

Answer 130.—That depends upon the size of the locomotive and the work it has to do. Most roads feel that 150 miles for valve oil and 50 miles for engine oil, per pint, is a record to be striven for.

Question 131.—How many drops are there in a pint of valve oil?

Answer 131.—The following table from a well known authority will show, and also give further data to determine the setting of injector feeds:

Capacity of Lubricators.	Total No. of drops contained in lubricator.	Number of drops for each cylinder per minute.	Hours consumed in feeding out a lubricator.	Total miles run on a basis of		Number of miles run to one pint of oil on a basis of	
				Passenger 30 miles per hour.	Freight 18 miles per hour.	Passenger 30 miles per hour.	Freight 18 miles per hour.
2 piuts. . .	13,200	5 drops . .	22 hours	660	396	330	198
3 pints. . .	19,800	5 drops . .	33 hours	990	595	330	198
Triple feed 3 pints. .	19,800	5 drops and 1 drop for air pump.	30 hours	900	540	300	180

Question 132.—What harm is done an engine by sand pipes being stopped up on one side?

Answer 132.—It produces a great strain, often breaking crack pins or rods, and also causes an uneven wear of tires.

Question 133.—In what ways are automatic bell-ringers operated?

Answer 133.—By air or by steam pressure.

Question 134.—Which is the better and more generally used?

Answer 134.—Air, because it does not condense or freeze and its exhaust does not obscure the vision, as does condensed steam.

Question 135.—Particularly in the western parts of the United States, what causes the greatest trouble with locomotives?

Answer 135.—Poor water. It has been estimated that the poor water on western railroads necessitates an additional expense of about $750 a year for each locomotive in service.

Question 136.—What is meant by poor water?

Answer 136.—Generally speaking, "hard" water, that is, water having incrustating matter which causes foaming and sometimes acids which eat into the flues and boiler sheets.

Question 137.—If these solids are in solution why should they cause trouble in a locomotive boiler?

Answer 137.—Because when such large quantities of water are evaporated, the solid matter remains as a sediment, some portions of which form a coating over the flues and sheets thus preventing the water from coming in direct contact with the iron. The result is the iron becomes overheated and cracks, and with all its overheating less heat is imparted to the water in the boiler.

Question 138.—How much of these incrustating solids are contained in a given quantity of hard water?

Answer 138.—This varies greatly, from two to twenty pounds per 1,000 gallons.

Question 139.—How can much of this solid matter be gotten rid of after the water is evaporated?

Answer 139.—By blowing it out of the boiler.

Question 140.—How is this done?

Answer 140.—One or more blow-off cocks are placed

in various parts of the boiler—generally just above the mud ring, as there is where the most of the sediment settles.

Question 141.—How are these blow-off cocks operated?

Answer 141.—By hand, or by pneumatic (or steam) pistons attached to the valves.

Question 142.—What effort is made by many railroads to overcome the bad effects of "hard" water?

Answer 142.—Some kind of boiler compound, such as soda-ash, is put in the locomotive tank each trip. This forms a chemical action with some of the incrustating solids causing less incrustation, but leaving more sediment which must be blown out or will cause foaming in boilers.

Question 143.—What other means are railroads adopting?

Answer 143.—The chemical treatment of water in large settling tanks located at the various water stations where poor water is had. The solids are allowed to settle and the clear and almost soft water above is pumped into the water tanks and then used for locomotives.

Question 144.—If your engine should get off the track with one or more wheels, how would you proceed to get it on again?

Answer 144.—Conditions vary in every case. If the wheels are close to the rails, block up with oak blocks or wedges to a pair of good wrecking frogs (car replacers) and run the engine up on the track. It is a general rule to follow, that an engine will go on best and most easily by retracing the path whence it got off.

Question 145.—In case of a derailment what should you do first?

Answer 145.—Look the situation over carefully, see how the engine stands, that the water and fire in the boiler are safe; if the wreck is serious telegraph for another engine and wrecking outfit; if not so serious, wire for another engine to help pull you on; if you think it possible to move the engine alone, put down some blocks and try it before sending for help.

Question 146.—If the rails are spread, to what gauge should they be spiked?

Answer 146.—Four feet, eight and one-half inches on straight track and about one-half an inch more on sharp curves.

Question 147.—After your engine is back on the track again, what would you look for?

Answer 147.—Broken driving box cellars, bent or sprung rods or crank pins, broken draw castings or draw bars, broken brake rigging, sprung axle or journal.

Question 148.—Suppose a driving box cellar or its lugs were broken, what would you do?

Answer 148.—I would make one of wood or in some way block on top of the binder sufficiently to hold the packing against the journal.

Question 149.—Why is it not safe to run an engine with a sharp flange?

Answer 149.—Because it is very likely to catch a switch point or a frog and cause a derailment, or the flange may break and cause a bad wreck.

Question 150.—Are there any locomotives that cannot run under their own steam with their side rods off?

Answer 150.—Yes, because of the extreme effort of modern builders to get long main rods and short straight eccentric blades. In order to do this the eccentrics are not placed upon the main driving wheel axle but upon

one of the driving wheel axles ahead thereof. Hence, with the side rods off the least slip of the main drivers would throw them out of tram with the driving wheel carrying the eccentrics, consequently such an engine would have to be towed in. This construction is becoming quite common for switching locomotives, which class of power is, of course, seldom out on the road where delays from breakdowns are most serious.

Question 151.—If you had, say, a disabled cylinder and had no drift to disconnect valve stem, what would you do?

Answer 151.—Take out top rocker arm pin, pull the valve rod an inch out of line with the top rocker arm and brace there securely by a notched-end stick. Disconnect the main rod and clamp the valve in center; and block crosshead, of course.

Question 152.—On very large locomotives with heavy rods is there any way to avoid taking down and loading up the main rod?

Answer 152.—Yes; if the main rod goes through a yoke at back of guides, take down the back end of main rod and block the crosshead ahead, letting the main rod rest in the bottom of this yoke.

Question 153.—In running an engine on one side how can you almost entirely prevent stopping on the dead center?

Answer 153.—By stopping the engine with the reverse lever, giving her a little steam. When the engine has stopped and before she starts to back up, set the brake hard, close the throttle and open the cylinder cocks.

Question 154.—Why will this be quite certain to keep the engine off the dead center?

Answer 154.—Because the power to stop the engine

being entirely in the cylinder of the good side, the greater power is on the quarter, and is nothing on the dead center to cause the engine to stop at that point.

Question 155.—In blocking a crosshead should you place it as far forward, or as far back as it is possible to do?

Answer 155.—No; put a small block at the front or back end of crosshead, as the case may be, in order to prevent all possibility of the piston packing rings dropping into the counterbore.

Question 156.—What harm would that do?

Answer 156.—It might necessitate the removal of the adjacent cylinder head; and if a back one it is a long, expensive job.

Question 157.—How would you arrange to run a mogul, or consolidation engine without the pony truck?

Answer 157.—Raise the engine in front and block between the cross equalizer and the belly of the boiler.

Question 158.—If a cast iron tender or engine truck wheel should break, what would you do?

Answer 158.—Try to block it from turning, and skid it to the nearest siding, running very slowly. Then chain up or remove the broken wheel.

Question 159.—Which man is the more economical of oil, steam, coal and time, he who continually carries a boiler too full of water or he who carries several inches less than a full glass?

Answer 159.—Most decidedly the latter. High water men make the poorest records and are the most extravagant, besides frequently breaking cylinder heads, shearing crosshead keys or breaking pins. If you keep close watch of the high water man on the road, you will find that there are many times when his water goes much

lower than the other man; for working wet steam first takes too much water from the boiler, then the water supply is increased, steam drops back, the reverse lever is dropped lower to make up for this loss of pressure; this takes still more water and if the run is long and hard it will be difficult to keep the water outside the lower water glass nut.

Question 160.—About what portion of the total power of a locomotive is wasted in friction?

Answer 160.—From 10 to 25 per cent., depending upon the effectiveness of the lubrication and the balancing of the valves.

Question 161.—What part of a locomotive has the greater friction resistance?

Answer 161.—The valve. But this is greatly reduced by well balanced valves.

Question 162.—What does proper lubrication prevent?

Answer 162.—It prevents wear, heat and resistance.

Question 163.—How much oil is useful and necessary for proper lubrication?

Answer 163.—Only the amount that can adhere to the frictional surfaces. Too much oil in cellars and on bearings only runs onto the ground or is thrown all over the engine; too much oil in cylinders only gums up the exhaust passages and nozzles.

Question 164.—What is the purpose of graphite, soap, ammonia, salt, etc., on a hot bearing?

Answer 164.—Chiefly to fill up or glaze over the rough spots in the bearing surfaces; also these substances will stand a greater heat than oil, before running off the bearing.

Question 165.—What is one frequent cause for hot bearings?

Answer 165.—The waste in cellars being too high at the sides, so that threads of it are caught up by the journal and wrapped around it, often catching fire when both journal and box are cold.

Question 166.—What is the best material for packing the cocks in the cab to keep them steam tight and still have them work easily?

Answer 166.—Fill the glands with plumbago or graphite, with a ring of asbestos wicking each side, then tighten down solid.

Question 167.—In case of impending collision, what should you do?

Answer 167.—Apply the brakes in emergency, shut off the throttle, whistle for brakes, open wide the sand lever, and then protect myself as my best judgment dictates.

Question 168.—Should a man make up his mind beforehand what to do?

Answer 168.—Most assuredly. When in great danger a man has little time for thinking and should act correctly from his premeditated determination. There have been many cases where men acting on the spur of the moment have released their brakes and done other things that tended not in the least to reduce the force of the collision.

Question 169.—With the modern large locomotives is it generally safer to jump off, or remain behind the boiler head in case of collision?

Answer 169.—That depends greatly upon the kind of collision. If a rear-end collision, less damage is likely to your locomotive. If a head-on collision with another large locomotive, I should "unload" at once. Going at moderate speed and in a safe place to jump, I would certainly get off. If it were in a cut the cars behind are

likely to pile up and render it as dangerous for you as it would be behind the big boiler head.

Question 170.—How is it known that a boiler is carrying the proper steam pressure?

Answer 170.—By the safety valves and steam gauge when the engine pops. No boiler should ever be allowed higher steam pressure than that prescribed by the company.

Question 171.—How should steam gauges and safety valves be tested?

Answer 171.—At least once a month by the use of a test gauge attached to the locomotive.

Question 172.—Why is it not better to remove the gauges and test them?

Answer 172.—Because the temperature of the gauge in the cab has some effect and the more certain way is to have the gauge in its usual position when testing.

Question 173.—How much power have the piston and crosshead on one side to turn the crank pin, when the center wrist pin, the crank pin, and the main driving axle on the same side are in a straight line?

Answer 173.—None whatever.

Question 174.—How then is the engine kept moving?

Answer 174.—The crank pin on the other side is on the quarter, and that being a most powerful position, this causes the wheels to move sufficiently to bring the opposite side off the dead center.

Question 175.—What is meant by "the dead center"?

Answer 175.—When the center of the wrist pin, the main crank pin, and the main driving axle are all in one straight line.

Question 176.—What is the "wrist" pin?

Answer 176.—The pin in the crosshead to which the front end of the main rod is attached.

Question 177.—How should hot bearings he treated?

Answer 177.—They should be cooled down gradually so as to prevent crystallizing and subsequent breakage of the metal. The cause should be ascertained, if possible, whether defective lubrication, foreign substances on the bearing, or defective workmanship, in order to guard against repetition of the same trouble.

Question 178.—What is the objection of filling a tank with water and overflowing it considerably?

Answer 178.—It wastes water, injures the roadbed, and in winter the water freezes up the flanges and has to be chopped out.

Question 179.—Should care be taken in opening the blow-off cock?

Answer 179.—Yes; always look first to see no one is near enough to be burned; also do not blow the water and sediment over cars, buildings, or over the engine and tender. It is very injurious to the paint and varnish.

Question 180.—What is meant by the "total wheel-base" of a locomotive?

Answer 180.—The distance from the center of the forward to back wheel of the engine.

Question 181.—What is meant by the "rigid wheel-base"?

Answer 181.—The distance between the centers of the front and the back pairs of driving wheels.

Question 182.—Why are piston rods frequently extended out through the front cylinder head?

Answer 182.—In order to better guide the piston and produce more uniform wear of the cylinders. This is the practice noticeable with the large cylinders of compound locomotives.

CATECHISM ON ELECTRIC HEADLIGHT.*

Question 1.—Are you operating an electric headlight? If so, how long have you had same, and what is the work required each trip to keep it in order?

Answer 1.—The commutator should be cleaned, a new carbon inserted in the lamp, the point of the electrode cleaned, and see that the proper amount of oil is in the bearing each trip.

Question 2.—Describe passage of current through lamp and tell how arc or light is formed.

Answer 2.—The current flowing from the dynamo is called the positive current and enters the lamp at the binding post and from there passes through a No. 8 insulated copper wire to the bracket, thence through connections to the carbon; then down through the copper electrode and holder to a No. 8 insulated copper wire, through the solenoid, then to the binding post and back to the dynamo. As soon as current passes through the solenoid, it attracts the solenoid armature, which in turn is connected with the levers which clutch the carbon and separates it from the point of the copper electrode. As soon as this separation begins, the current jumps from the carbon to the electrode, and as the distance is increased the current becomes stronger in its effort to jump from one point to the other, and at the same time the current going through the solenoid becomes weakened and

*In this connection the reader is referred to volume 2 pages 405 to 428 of this series devoted to a description of the appliances of locomotives.

releases the solenoid armature until the distance between the carbon and the electrode points is properly adjusted to form the arc. As the carbon gradually burns away and the distance from the carbon and electrode becomes greater, the current becomes weaker going through the solenoid and the carbons are again drawn together by the tension spring until the proper arc is re-established.

Question 3.—If light burns all right while engine is standing, but dies down while running, where would you look for the trouble? How would you remedy it?

Answer 3.—If the light burns all right while the engine is standing but dies down while running, it is an indication that the carbon is jarring through the clutch faster than it is consumed and the clutch spring should be strengthened so as to hold the back edge of the clutch from being jarred upward and thereby releasing carbon. This may also be caused by the tension spring being too tight, thereby forcing the carbons too close together to form the proper arc.

Question 4.—If the light flashes and goes out, and repeats this several times, then goes out entirely, what would be the cause?

Answer 4.—This is probably caused by the carbon being very nearly burned out and the holder is fed down so that it just touches the clutch and the jar of the locomotive causes it to flash. This possibly might also be caused by a broken wire under the insulation, or both wires being jarred together where there is no insulation —it means a short circuit somewhere.

Question 5.—If the light burns all right when engine is standing, but dies down when running, and the faster you run the more the light runs down, what causes it to die down?

Answer 5.—This condition is caused by the same trouble as in question No. 3 and should be handled the same, for the reason that the faster the locomotive runs, the more jar there is and the more apt the carbon is to jar through the clutch.

Question 6.—If light dies down when you pull out from station, what is the matter?

Answer 6.—This trouble is caused by having too much water in the boiler and working wet steam in the turbine engine.

Question 7.—If your light flashes and goes out for a second, then burns brightly for a second, and keeps this up, where would you look for the trouble?

Answer 7.—It is probably caused by a broken wire, a loose wire in the binding post, or insulation worn off both wires, allowing them to be jarred together. Examine your lamp thoroughly, and see that all screws are tight and insulation good.

Question 8.—If your light burns very dim and engine is working hard, and cab lights are bright, where is your trouble?

Answer 8.—This condition is caused by a short circuit and is probably in your incandescent wiring. The first thing to do is to pull out one of the incandescent wires from the screw, which will determine if the short circuit is in the incandescent wiring. If this does not remedy the trouble, look for a "short" in your lead wires between the dynamo and lamp.

Question 9.—What should you be sure of, when putting in carbons?

Answer. 9.—In putting in a carbon you should be sure that the carbon is smooth and straight and will fall through the clutch freely.

Question 10.—If copper electrode burns off during the trip, state probable cause. What effect does it have on the light? Can you prevent it burning more? If so, how?

Answer 10.—The probable cause of electrode burning off during the trip is the speed of dynamo being too high. This is shown by a green light instead of a white light. The burning of the electrode can be stopped at once by throttling the steam on turbine which reduces the speed for the time being and then, when you get to the end of your trip, you can report the governor and have the speed readjusted.

Question 11.—Why should the copper electrode be clean both on point and where it passes through holder?

Answer 11.—The copper electrode should be clean on the point so that the top carbon will touch the copper, for if there is any scale on the end of the copper, it will prevent the carbon from touching the copper, and you will therefore not get the proper contact which you must have to get a current. It should also be clean where it passes through holder so that the current will pass from holder to the copper freely, as any foreign substance has a tendency to insulate the copper from the holder.

Question 12.—Give different causes for light burning green. What must be done to stop it burning green?

Answer 12.—The cause for the light burning green is that the copper electrode is burning. This may be caused by the speed of the dynamo being too high, or by the wires from the dynamo to lamp being connected up wrongly, so that the positive current enters the copper electrode instead of the top carbon. In this case the binding posts should be changed on the dynamo.

Question 13.—If commutator becomes rough and out of round, what should be done with it?

Answer 13.—It should be trued up, which can be done very nicely, if not too badly out of round, by holding a strip of sand paper by the ends on the commutator when it is running. If pretty bad, it should be put in the lathe and trued up, using a very sharp tool for the work, after which the mica strips in the commutator should be filed out a trifle below the surface to be sure that the copper strips do not lag over.

Question 14.—How, and when should the commutator be cleaned?

Answer 14.—The commutator should be cleaned at the end of every trip. This should be done with a piece of damp waste endwise on the commutator, and then finished with a dry piece of waste. It is not necessary to use sand paper unless the commutator is rough and sparks.

Question 15.—What is the bad effect of holding sand paper except by ends?

Answer 15.—The bad effect of sand paper on the commutator except when held by the ends is to increase the low spots, as the sand paper would then reduce the copper at the low spots as well as the high, where if the sand paper is only held by the ends, it only reduces the high spots on the commutator and therefore trues up the surface.

Question 16.—Why should mica strips in commutator be kept below copper?

Answer 16.—For the reason that the copper, being softer than the mica, wears away more rapidly and therefore the copper becomes a trifle lower than the mica, and the brushes passing over this mica cause the sparking on the copper.

Question 17.—Why should sand paper be used on commutator and not emery cloth?

Answer 17.—Sand paper should be used on commutator, as should there be a piece of sand paper left between the commutator bars where the mica is filed out, the current would not pass through the sand, but the emery being a conductor of current under these circumstances, would cause a short circuit, by allowing the current to pass through the emery.

Question 18.—Do you put any oil in turbine? What kind and how often?

Answer 18.—The turbine engine should be oiled at least once a week to prevent scale on the buckets. Black oil is recommended for this.

Question 19.—How and when do you oil armature bearings?

Answer 19.—The middle bearing should have just oil enough in the cellar to allow the ring in revolving to pass through it and carry the oil up on the shaft. It is very easy to tell when more oil is required by removing the oil cap and noticing whether the ring is carrying the oil. The outside bearing on the cap should be oiled about every trip.

Question 20.—What is the purpose of tension spring No. 93?

Answer 20.—The purpose of tension spring No. 93 is to overcome the pull of the solenoid on the solenoid armature, preventing the same from separating the points of the carbon too far and breaking the arc.

Question 21.—If too tight, does it affect light burning with low steam pressure? If too weak?

Answer 21.—If tension spring No. 93 is adjusted too tight, it will prevent the engine from running with low

steam pressure, as, by forcing the carbon points together, the current is not consumed and is therefore backed up into the dynamo which creates a heavy current. If adjusted too weak, it will allow the solenoid to separate the carbon points too far, thereby breaking the arc.

Question 22.—If commutator sparks badly what would you do?

Answer 22.—If the commutator sparks badly and the sparking cannot be stopped by the adjustment of springs on the brushes, it should be trued up with sand paper as stated above, and then if the sparking does not cease, the face of the brush should be refitted to the commutator.

Question 23.—Why should commutator be cleaned endwise and not round?

Answer 23.—If the commutator is cleaned "round," there is a tendency for dirt to lodge in the creases between the copper strips, which allows the current to pass through the dirt; the commutator should therefore be cleaned lengthwise, so that these creases will be kept clean.

Question 24.—If light does not start when turning on steam, what would you do?

Answer 24.—The point of copper should be examined to see that there is no foreign substance to prevent the carbon touching it, that the proper tension is on the brushes and that the commutator is clean, and then if the light does not start, a carbon or piece of wire or something which will carry current, should be placed across the binding posts and then removed suddenly. If there is a flash upon removing same, the dynamo is all right and then if the light does not start, the trouble is in the lamp.

AIR BRAKE—MISCELLANEOUS.

Question 1.—Trace the air through the air brake system.

Answer 1.—The air is received from the atmosphere through the air cylinder of the pump; from there it passes through the discharge valve and pipe to the main reservoir; thence through the brake valve to the train pipe; through the branch pipe, cut out cock and triple valve to the auxiliary reservoir (to charge); then from the auxiliary through the triple valve to the brake cylinder (to set the brake), from the cylinder again back through the triple to the atmosphere (to release the brake). When a retainer is used the final exhaust from the triple has to pass through the retaining valve.

Question 2.—Should the engine equipment be tested before leaving the engine house?

Answer 2.—It certainly should, and be known to be in good working order.

Question 3.—How should this test be made?

Answer 3.—Open the bleed cocks in main and auxiliary reservoirs, start the pump slowly, lubricate it properly, observe about the number of strokes required to compress from 40 to 50 pounds, open the rear and front signal and train line cocks to see that they are working and not frozen, see that the governor and the feed valve are properly regulating the pressures and that the pump stops working, indicating no leaks; then apply a service application and see that the brakes remain set at least three minutes and that the pistons have proper travel; release and see that they release all right.

Question 4.—What is your first duty after coupling onto a train?

Answer 4.—Charge the train fully and see that the trainmen fix any leaks.

Question 5.—Should the brakes be tested before leaving a terminal?

Answer 5.—Always.

Question 6.—How should this terminal test be made? Explain in detail, giving trainmen's duties also.

Answer 6.—Beginning at the rear, the brakeman should couple all the hose, open all the angle cocks except the one at the rear, see that all the cars are cut in (except such as are marked defective), see that all the hand brakes are off, and the retainers open, with the handles pointing down. The engine should be cut in last. While the engine is charging the cars, the brakeman should pass along the train and inspect it carefully to ascertain if there are any leaks. In charging a train the pump should be run according to the temperature of the weather, in order to charge the train reasonably fast without overheating it. Where there are average leaks, an eight inch pump should charge a train in about one-half as many minutes as there are cars; a nine-and-one-half inch pump twice as quickly. After the train is charged and the engineer is satisfied that it is reasonably free from leaks, the head brakeman (stationed at the head air brake car) should signal the rear brakeman (stationed at the rear air brake car) who should repeat the signal. After the engineer gets the signal from the rear man, he should apply fifteen to eighteen pounds in service application and place the engineer's valve handle on lap. The brakemen should now walk toward each other, inspecting each car, to see that it sets and holds—noting the piston travel as

well. After this has been done, they should signal the engineer to release. He having done so in release position, the brakeman should pass each to his respective end of the air brake cars to see that all the brakes have been released, and, in winter, see that no shoes are frozen to the wheels. The head brakeman should then advise the engineer as to the number of air cars that are in good working order, and the tonnage or length of the train.

Question 7.—Why is a terminal test necessary? Or, is it only advisable?

Answer 7.—tI is necessary to insure the safety and celerity of the train on the road.

Question 8.—What test is necessary after coupling up, when air brake cars have been separated for a crossing, or make-up of train changed?

Answer 8.—To know by trial that the engineer can set and release the rear cars in the train. If the make-up of the train has been changed and any cars added; besides noticing the rear cars, a regular terminal test should be given the cars just picked up.

Question 9.—What is meant by a running test? How and where is this test made?

Answer 9.—A test of the air brakes while the train is moving. It is good practice to make a running test of the brakes at the summit of heavy grades, also two miles from important points, meeting points, railroad crossings, etc. On passenger trains a sufficient reduction (8 to 10 pounds) should be made to feel the brakes holding well, also noticing the length of the blow from the train line exhaust. On long freight trains, releasing brakes while moving is such poor practice that it is generally better to make only a three or four pound reduction for a running test, determining the length of the train from the train line exhaust.

Question 10.—What is the leakage groove in the brake cylinder for?

Answer 10.—To allow the air to pass by the piston and not set the brake when the train pipe pressure is reduced slowly by ordinary leakage. This groove is long enough so that the piston has to travel over 3 inches to cover it, and is in the back end of all cylinders except driver brakes.

Question 11.—In making a service application, what should the first reduction be? Explain why.

Answer 11.—From 5 to 8 pounds, sufficient to get all pistons by the leakage grooves. With 10 to 15 cars, 5 pounds would do this, with 50 to 60 cars, 8 pounds would be necessary.

Question 12.—Does a long train require a heavier reduction than a short train? Why?

Answer 12.—Yes, because the train line exhaust opening is the same size for all length trains, hence the longer the train, the slower the reduction in train pipe pressure and the slower the pistons move past their leakage grooves; unless the reduction is continued until each piston passes the leakage groove, that brake will not apply in making the stop, or if it does set later it will be with a less pressure.

Question 13.—From a seventy-pound train pipe pressure, how much of a reduction will be required to apply the brakes in full?

Answer 13.—From 18 to 20 pounds with an 8 inch piston travel—the greater reduction on long trains on account of more loss at the leakage grooves.

Question 14.—Has the piston travel anything to do with the pressure obtained in the brake cylinder?

Answer 14.—Yes, the shorter the travel (if beyond the

leakage groove) the greater the pressure, as the space to fill is so much smaller.

Question 15.—With proper pressure and proper piston travel, what is the brake cylinder pressure with a full service application? With an emergency application?

Answer 15.—About 50 pounds in service; about 60 pounds in emergency with the quick action triple.

Question 16.—Is there any difference in these brake cylinder pressures with different forms of triples?

Answer 16.—Yes, with the plain triple there is no greater pressure in the cylinder from emergency than from service application.

Question 17.—How should you apply and release the brakes on a part air-braked freight train? How on a very long all-air train?

Answer 17.—Shut off and let all the slack that will run in, then make the first application as per answer No. 11 above. Increase the application as necessary. To release this part air train if necessary while moving, let off a few brakes at a time by placing the brake valve in running position a second and back to lap several times in slow succession; when you think they are all off, to full release, then running position, and let the slack run out before carefully working steam. With a very long all-air train it is practically impossible to jerk the train, no matter how you apply the brakes in service. First reduce 8 or 9 pounds, then 10 to 15 more as is necessary to stop. If avoidable, do not release *at all* when moving or you will likely break the train in two, especially when moving very slowly. If necessary to release at the foot of a grade, do so while the rear part of the train is still on the hill. If you have an independent, or straight air brake on the en-

gine, keep it set tight until the train brakes are all released.

Question 18.—How would you make a two-application stop with a passenger train?

Answer 18.—If fast time is to be made, run fast up near the station, apply 10 to 15 or even 20 pounds in service, when the train is down to about 15 to 20 miles per hour speed, release in full release and back to lap; then apply with two or three 5 pound reductions, as necessary to stop right.

Question 19.—How and when would you release the brakes on a short passenger train? On a long passenger train (over ten cars)?

Answer 19.—Release the brakes on a short passenger train just 5 or 6 feet before stopping; on a very long passenger train, release 10 or 12 feet before stopping. More depends upon how much pressure you have in the brake cylinders than on the length of train. Try to release just as early as you can and still not let the train run along.

Question 20.—How and when would you release the brakes on a short freight? How on a long freight train?

Answer 20.—Not until the full stop is made on any length freight train, if it can be avoided. See answer to No. 17.

Question 21.—How should a stop at a water tank or coal chute be made with a long freight train?

Answer 21.—Stop a few car lengths short; cut off the engine to take coal or water.

Question 22.—In switching with an air brake train, and picking up uncharged cars, how should you handle engineer's valve?

Answer 22.—A high main reservoir pressure will release a low auxiliary pressure; hence, before coupling

to the uncharged cars see that this condition exists even if you have to set and release the brakes (without re-charging) you have coupled to the engine. When coupled up, the handle on lap and a high excess pressure, you will be able to release and move at once. Leave the valve in full release until the gauge hands begin to rise.

Question 23.—When applying the brakes in service, can you detect if any brake sets quick action? Explain.

Answer 23.—If standing, by the train line exhaust; if moving, also by the jerking of the train. If the exhaust from the train line stops suddenly while the valve is in service application position (it may or may not start again according to how much reduction is made), it shows that the train pipe pressure has dropped faster and lower than the pressure in Chamber "D." Emergency does this by venting part of the train pipe pressure directly to the brake cylinders.

Question 24.—If one quick action triple goes into emergency, will the others follow? How will you locate this defective triple?

Answer 24.—Yes; if it is a quick action triple all the other triples of either kind will go to emergency. Rare exceptions to this rule may occur where a large number of plain triples, or cars having brakes cut out are placed together in a train. One method is to set about 5 pounds in service application and then find out which cars having quick action triple valves have not set; have someone watch each car while increasing three to five pounds more in the service application. The car that sets in quick action first is the defective one, but as emergency travels at the rate of about twenty-three cars per second, it is best to cut out one of the cars that did not set at the first reduction, and have the application continued; if this

proved not to have been the one thus defective, test the train again, cutting out another car that failed on the first application, until the defective car is located. Another and ordinarily shorter method is as follows: Cut the air cars in two equal sections and repeat the test for trying brakes. This will tell which half of the train is defective. Then take one-quarter or three-quarters, according to whether the defective car is in the front half or back half of the train, and continue in this way (never trying with less than three car lengths of piping) until the defective car is found and cut out. A broken graduating pin in the quick action triple, or a sticky triple piston will cause a brake to set quick action, and although this rarely occurs, no train should be taken out of the station until the defective car is located and cut out. It sould be done before damage occurs.

Question 25.—Should the brakes be released before uncoupling from train? Why?

Answer 25.—Yes, in order that the cars can be switched and the car repairers can tap (test) the wheels or jack up a journal box; also to prevent shoes from freezing to the wheels, and especially because a brake that is applied leaks so rapidly that in changing engines it may be found that much of the air has escaped.

Question 26.—In descending a grade how can you best keep a train under control?

Answer 26.—The best way is to apply the air lightly while the train is moving slowly, keep the train at a slow speed, and the train-line pressure as high as possible all the time. To do this, if it is necessary to recharge, reduce the speed below the average just before recharging. To recharge, handle the train as though a flagman had been

seen half a mile ahead, that is, go slowly and exercise caution.

Question 27.—In what position would you carry the brake valve handle between applications of the brake while descending a grade? Why?

Answer 27.—Full release up to the standard train line pressure, because you can thus charge up the more quickly.

Question 28.—How rapidly does an auxiliary charge from fifty to seventy pounds? When should you bear this in mind particularly?

Answer 28.—About half a pound a second. In making a second application soon after having released.

Question 29.—Explain the operation of the pressure retaining valve. What is its use?

Answer 29.—It is a weighted valve which the triple exhaust from the cylinder has to raise in order to escape when the handle is turned up, before the brake is released. It causes the release to be slower, and finally holds from 15 to 20 pounds pressure in the brake cylinder while the auxiliary reservoir is being recharged.

Question 30.—How many pounds of air is it intended to close up on, and hold in the brake cylinder?

Answer 30.—Fifteen to twenty pounds.

Question 31.—Does the brake release any slower until it gets down to this pressure?

Answer 31.—Yes, see answer 29.

Question 32.—Name the defects which cause the retaining valve to be ineffective.

Answer 32.—Dirt under valve, cock leaking, retainer pipe leaking.

Question 33.—How do you make a test of retaining valves?

Answer 33.—Reduce 10 to 15 pounds train line and then release with the retainers turned up. The retainer should hold the brake set at least two minutes.

Question 34.—When brakes go on suddenly without the action of the engineer, what are the causes? And what should you do?

Answer 34.—The train has parted, a hose has burst, or a valve has been pulled open. Shut off at once under all circumstances and place the brake valve on lap as quickly as possible.

Question 35.—If you found the train was broken in two, how would you proceed to get under way again promptly?

Answer 35.—When the train has been brought to a stop, I would place the handle in running position to see if the train pipe is still open. If I thought it was a burst hose, I would keep the handle moving from lap to running position and back, so that the trainmen could hear the air escaping from the burst hose. If I find that the black hand is gaining in running position, I would know that the trainmen had found the defect and had closed the angle cock ahead of it. I would then release the head brakes and lap the valve, so as to pump up excess ready to release the rear cars when the hose had been replaced, or the train recoupled if it had been parted.

Question 36.—How would you proceed in case of a bursted hose? How can you help trainmen to locate it?

Answer 36.—By occasionally throwing the brake valve to release and back to lap.

Question 37.—Why is it dangerous to apply and release the brakes repeatedly on grades, and at station stops?

Answer 37.—If the auxiliary reservoirs are not given

time to recharge between applications, there will not be sufficient pressure left with which to make a stop.

Question 38.—When two or more engines are coupled together, which engineman should do the braking? What should the other engineman do?

Answer 38.—The head engineman. Close the cut out cock underneath each brake valve, except the head one, place the valve in running position and keep the pump running in case of necessity.

Question 39.—Why is it important to have driver brakes in good order?

Answer 39.—Because they are the most powerful brakes on the train, are used the most, keep the tires worn down and prevent the engine from pulling away from the tank or train.

Question 40.—How would you test for leaks in driver brakes?

Answer 40.—Make four 5 pound reductions (and see that they apply with the first) and they should remain set at least three minutes. If not, set fully or in "straight air" and examine with a torch all joints and pipes from the triple valve to both cylinders and all parts of the latter.

Question 41.—Would you reverse an engine with the driver brakes applied? Why?

Answer 41.—Not if the brakes were in good order; because it would slide the wheels and not stop as quickly.

Question 42.—What is the proper piston travel for engine brakes? For tender brakes? For car brakes? Explain how each is adjusted.

Answer 42.—Generally speaking the piston travel should be kept between one-half to three-fourths the length of all kinds of brake cylinders except drivers. It is ad

visable, however, that freight cars be taken up to five inches when empty and drivers are best kept between two and four inches. It occurs in the practice of some companies, that engine trucks, and ore cars or other cars of special construction have cylinders but eight inches long. In passenger cars the slack is taken up by the turn-buckles or dead levers. In freight cars and tenders it is taken up by the dead levers, or bottom rods for inside connected brakes. In cam driver brakes, it is taken up by lengthening the arms, and in truck brakes by lengthening the outside arms.

Question 43.—What is the percentage of braking power on an engine? A tender? A passenger car? A freight car?

Answer 43.—About 70 per cent; 100 per cent of its weight without coal or water; 90 per cent passenger and about 70 per cent for empty freight cars.

Question 44.—Do you consider a good light on the air gauge as important as on the steam gauge? How often and at what places should you look at the air gauge?

Answer 44.—Yes, more so, as steam is indicated by the working of the engine, while, until ready for its use, there is no certain indication of the amount of air pressure except by the gauge, which must be clearly seen. Clear vision of the air gauge at night is very important, and should be given proper attention; the light from the fire-box when the door is open is not sufficient. When whistling for road crossings, or other similar places, and about two miles from all dangerous places, or places where the train is to stop, the gauge should be examined particularly.

Question 45.—Do you appreciate the fact that handling the air brakes is a task requiring skill and close at-

tention, to insure the comfort of passengers and the safety of freight and cars?

Answer 45.—I do.

Question 46.—Do you understand that a failure of air brakes to work is invariably due to the failure of some man to do the proper thing at the proper time?

Answer 46.—I do.

Question 47.—Do you understand that all brakes must be kept in good order to give proper service, and that proper reports of their condition must be made by men operating them to insure their maintenance?

Answer 47.—I do.

SUPPLEMENTARY EXAMINATION HELPS

FIRST, SECOND AND THIRD YEARS

FIRST YEAR

Q. Have you acquired the habit of comparing time with your engineer, and do you insist on seeing the train orders, as provided for in Transportation rules, under the head, "Rules for Movement by Train Orders?"

A. I do.

Q. Do you thoroughly understand all the signals on the road?

A. I do.

Q. In addition to the regular danger signals of the company, what else do you consider a danger signal?

A. If between stations at night, any kind of a light vigorously waved on the track. If in daytime someone should be seen waving a flag or hat, on, or alongside the track ahead of the train, I would consider it a danger signal.

Q. If you should discover that a fixed signal is missing or imperfectly displayed, what is your duty?

A. To notify the engineer at once.

Q. What is the main difference between bituminous and anthracite coals?

A. Anthracite coal contains more fixed carbon, and

gives out very little flame or combustible gases during the process of burning and it also burns very slow as compared with bituminous coal.

Q. What is carbon, and whence do we obtain oxygen?

A. Carbon is the main element of organic nature. The oxygen necessary for combustion is supplied from the atmosphere.

Q. What per cent of oxygen is in the atmosphere?

A. By volume, 21 per cent; by weight, 23 per cent.

Q. About what per cent of carbon is there in bituminous coal?

A. About 80 per cent.

Q. What other heat-giving properties are there in bituminous coal?

A. Hydrogen; about 5 per cent.

Q. What is the appearance of a fire when it is at a very high temperature?

A. It burns with a clear, white color, giving off very little black smoke.

Q. Is it necessary to prevent black smoke? If so, why?

A. It is necessary to use every effort to prevent it—first, for economical reasons; second, on account of certain city ordinances.

Q. Has a locomotive a natural or forced draft, while working?

A. Forced draft.

Q. What is the object of having exhaust steam go through the stack?

A. To create a partial vacuum in the front end, and thus aid in causing a forced draft.

Q. When the fuel burns mostly in the front end of the firebox, what does it denote?

A. That the diaphragm should be slightly raised.

Q. When it burns mostly under the firebox door, what does it indicate?

A. That the diaphragm should be slightly lowered

Q. How can these defects be remedied?

A. By properly adjusting the diaphragm.

Q. Why are grates made to shake, and when should they be shaken?

A. To keep them free from ashes and clinker.

Q. What will result from allowing the ash pan to fill up?

A. It will prevent the proper admission of air to the firebox, and the ash pan is liable to become warped.

Q. What is the proper method of using dampers?

A. The damper should be given the amount of opening that will admit the proper quantity of air. It is best to admit most, or all of the air if possible, through the back damper opening.

Q. Why are the holes in the firebox door, and deflector inside of furnace a benefit?

A. For the purpose of admitting air above the grates.

Q. Do you think it is to your own and the company's interest to assist the engineer in the performance of his duties?

A. Yes, when I can do so without neglecting my own duties as a fireman.

Q. What are the advantages of a large grate area?

A. The admission of sufficient air to supply combustion needs of heavy working engines.

Q. What are the duties of a fireman on arrival at terminal, regarding dampers and signals?

A. He should take in his flags or extinguish his lamps, and see that the engine has sufficient fire and water to last until the hostler gets around. The dampers should be left as near closed as possible.

Q. Do you consider it essential to your success in the business to abstain from the use of intoxicating liquors?

A I most certainly do.

Q. Do you consider it to your interest to keep the engine you are firing in as cleanly a condition as possible under the circumstances?

A. I certainly do.

Q. Do you consider it to your interest to cheerfully comply with all orders emanating from your superior officers?

A. I do.

SECOND YEAR

Q. If the fire were not getting air enough through the grates why not partially open the door to supply the deficiency?

A. Because the admission of air through the door has a tendency to cool the gases, thereby causing a loss of heat.

Q. How can you admit too much air?

A. By leaving the dampers wide open, also by leaving the door open between shovels full of coal.

Q. In the case of an engine working hard, and using bituminous coal, do you think it possible to admit too much air through the fire?

A. Not if all the air admitted passes up through the grate.

Q. What is known as the leg of a boiler?

A. That portion of the boiler which forms the four sides of the firebox.

Q. What parts are surrounded by water, and why?

A. All portions of the heating surface, including the side sheets, crown sheet, flue sheet, flues and end sheets. To prevent overheating.

Q. What is commonly termed a "wide" firebox?

A. A firebox which extends outward over the back drivers, or trailers.

Q. What is the object of having wide fireboxes?

A. To obtain increased heating surface and larger grate area.

Q. For what reason are boilers constructed with "wagon tops?"

A. In order to obtain a sufficiently large firebox, also larger steam space.

Q. How is circulation assisted by use of arch tubes?

A. The water in the tubes being heated very rapidly, is constantly passing out of the tubes at the top, while water at a lower temperature is entering the tubes at the bottom.

Q. What are the principal causes of water being carried over into the cylinders from the boiler?

A. Priming and foaming.

Q. In the event of losing the water in the boiler from any cause, how would you be governed?

A. Would smother, or knock out the fire as quickly as possible, so as to prevent damage to the firebox sheets and flues.

Q. Are you familiar with the benefits to be derived from superheating?

A. I am. Service tests have shown a saving of 33 per cent in fuel consumption, effected by superheating the steam.

Q. Have you consulted any recognized authority as to the amount of water that ought to be evaporated in a locomotive boiler to the pound of fuel?

A. I have.

Q. Why is netting placed in the front end of coal-burning locomotives?

A. To prevent the sparks from passing out through the stack.

Q. What is the least depth of water on crown sheet that is safe?

A. Four inches.

Q. Would you feed oil as fast for a speed of fifteen miles per hour as for a speed of thirty miles per hour?

A. The faster the speed of the engine, the more oil is required in a given time.

Q. Name a few of the principal troubles that are to be looked for on a locomotive.

A. Bursted flues, injectors working badly, boiler foaming or priming, hot bearings (including eccentrics), break-downs of valve gear, main rods and side rods, pistons, valves, etc.

Q. What is a dry valve, and how can it be located?

A. A valve is dry when it is not receiving enough oil.

Q. If the sand-pipe on one side of an engine becomes clogged is it advisable to sand the rail from the other side only?

A. It is not.

Q. Are you familiar with the construction of Stevenson and Walschaert valve gears?

A. I am.

Q. Are you on good terms with your engineer, and do you discuss matters with him pertaining to your business, and are you interested in his train orders, etc.?

A. My engineer and I are good friends, and we do discuss matters pertaining to our business; I also am interested in the train orders.

Q. Do you consider it to your interest to work to the best of your ability for the interests of your employer, and be economical in the use of fuel and supplies?

A. I certainly do.

Q. In the event of blower becoming disconnected, how could you create a draft on the fire?

A. Would keep the grates free from ashes and clinkers, and would keep the ash pan clean; also break the coal into lumps of the proper size, and endeavor to keep the fire as light as possible.

THIRD YEAR.

Q. Why must the rails be sanded before starting?

A. In order to prevent the engine slipping.

Q. In case the boiler failed completely, how would you prepare to be towed?

A. Would disconnect both main rods, and block both cross heads forward, putting a small block at forward end of cross head. Disconnect and take down eccentric rods and straps, both sides, and place them on the tender. If in cold weather would drain all water out of boiler and pipes in order to prevent freezing.

Q. What is the principal cause of more broken cylinder heads, packing rings and intermediate heads than any other one thing?

A. Water in the cylinders, caused by boiler foaming or priming. Another cause is reversing engine when running at high speed.

Q. Can the lengths of the side rods of an engine be altered by keying in any other position than on the center?

A. Yes. Side rods should never be keyed except when engine is on center, and should be tried on both forward and back centers.

Q. What would you do in case you lost a rod key?

A. If I had no extra key to replace it would disconnect, and proceed with one side.

Q. When necessary to disconnect main rod, is it necessary in all cases to block crosshead?

A. Yes.

Q. If an engine pounds when steam is shut off, what would it indicate?

A. Main rod keyed too long, or a loose follower bolt.

Q. How fast would you run with broken tires?

A. Would run slow and carefully.

Q. Is it your duty as an engineer to supervise and direct the fireman in his work upon the engine?

A. It is.

Q. Do you understand that it is your duty to so familiarize yourself with the locomotive and its appliances as to do necessary work while on the road and report repairs intelligently on the work book?

A. I do.

Q. What benefits are derived from flange lubricators, and how operated?

A. Reduces friction. Should be watched closely.

Q. What should be done to lubricate cylinders while drifting?

A. Increase the oil feeds.

Q. What is the cause of injector spilling steam and water at the overflow when the injector is working?

A. Obstructed flow of steam to injector throttle. Check valve partly lifting.

Q. What is the object of having a blow-off cock in the water leg of a boiler?

A. In order to blow out the sediment, most of which settles there.

Q. Explain the principal difference in two radically different piston valves.

A. One type is hollow and the steam flows through lengthwise. It is also lighter and more evenly balanced than is the other type which is solid.

Q. Why are valves given lap?

A. First, that the steam may be cut off before the piston reaches the end of its stroke, thus utilizing its expansive properties. Second, it causes the exhaust port at one end of the cylinder to be opened before the steam port at the other end is uncovered for the admission of steam.

Q. In the event of a valve stem becoming broken on an engine equipped with the Young valve, how may engine be put in safe condition?

A. Disconnect valve rod, and place and secure the wrist plate in its central position.

Q. How is the Young valve operated?

A. By the Stephenson gear, with the addition of a wrist plate located between the cylinder saddles and the steam chests, and which rotates on trunnioned bearings.

COMPOUND ENGINES

Q. What is the difference between a four-cylinder tandem, a Vauclain, a balanced, and a Mallet compound in arrangement of cylinders?

A. The tandem has one cylinder behind the other. The Vauclain has one cylinder above the other. The balanced has four cylinders, the two high pressure being placed between the frames, and the low pressure cylinders outside. The Mallet has two complete sets of driving wheels, and the two high pressure cylinders are connected with the rear set, while the two low pressure are connected with the forward set.

Q. How many main steam valves has each type?

A. The tandem has four, the Vauclain two, the balanced two, the Mallet four.

Q. Why are the low-pressure cylinders made larger than the high-pressure?

A. To obtain necessary piston area.

Q. What does it mean to "simple" a compound engine, and when should it be done?

A. Working live steam in high and low pressure cylinders. Only in starting a heavy train; or while ascending a steep grade.

Q. When a train is ready, how should a compound engine be started and what should be observed?

A. See that the rail is first sanded, and be sure to have the cylinder cocks open.

Q. In case it is necessary to disconnect low-pressure main rod on balanced compound, what would you do?

A. Remove low-pressure piston, replace the cylinder head, and run that side as a single expansion engine.

MALLET COMPOUNDS

Q. How do you test for high-pressure valve blow on Mallet engines? How for low-pressure?

A. For high pressure valve proceed in the same manner as for simple engine. To test low-pressure valve, place valve central, then admit high pressure steam from boiler through receiving pipe, by opening starting valve slightly.

Q. Describe the articulated feature of the Mallet compound.

A. Two sets of drivers, each having an independent set of frames, cylinders, pistons, cross-heads, connecting rods, and valve gear, all under one boiler, the two sets united by a flexible joint. The meaning of the word "articulated" is jointed.

WALSCHAERT VALVE GEAR

Q. Describe in a general way the difference between Walschaert and Stephenson valve gear?

A. The Walschaert valve gear requires but one eccentric, or its equivalent, while the Stephenson requires two eccentrics. The Walschaert gives a constant lead, but with the Stephenson the lead varies with the point of cut-off. The Walschaert gear is placed outside of the drivers, is more accessible than the Stephenson. There is

much less friction in the Walschaert than in the Stephenson gear.

Q. How are the valves given lead with Walschaert gear?

A. By means of the combination lever, receiving *its* motion from the cross-head.

Q. When engine is reversed, does it change the motion from direct to indirect?

A. Yes, with the Walschaert valve gear.

Q. When engine is in forward motion, where is the link block, at top or bottom of link?

A. That depends upon the design of the gear. The usual practice in American design brings the link block in the lower half of the link when engine is in forward motion.

Q. With Walschaert gear, how can you tell whether valve is outside or inside admission?

A. With outside admission the eccentric crank is located 90 degrees ahead of the main crank pin; the valve stem being connected to upper end of combination lever, with radius rod connected beneath it. With inside admission, eccentric crank is 90 degrees behind crank pin while the radius rod is connected to upper end of combination lever, with valve stem beneath it.

BAKER-PILLIOD VALVE GEAR

Q. Explain the principal of the Baker-Pilliod valve gear.

A. With this valve gear the motion of the valve is derived from two independent sources, viz.: the crank pin through an eccentric crank set at right angles to the main

crank, and connection to the cross-head through a swinging lever. In place of the link, a reverse yoke is employed.

Q. In case of broken eccentric crank or eccentric rod, how would you disconnect an engine having Baker-Pilliod valve motion?

A. Proceed in a similar manner as with the Walschaert valve gear.

SUPERHEATER

Q. What is a superheater?

A. A device for imparting a higher temperature to the steam than is due to the temperature of the water from which it has been generated.

Q. Trace the steam from boiler to atmosphere on an engine having a superheater.

A. After leaving the boiler, and before passing to the valve chests the steam passes through a system of pipes or coils, termed a superheater, located in the smoke box, and is thus superheated.

Q. From where is the heat obtained that is imparted to the steam passing through the superheater?

A. From the waste gases in their passage through the smoke box.

Q. Does superheating steam increase or decrease fuel consumption?

A. Fuel consumption is greatly decreased by superheating steam.

Q. What is the temperature of saturated steam at 160 pounds pressure?

A. Three hundred and seventy degrees.

Q. Approximately, how many degrees additional temperature are obtained by superheating?

A. One hundred and twenty degrees.

Q. How does this temperature compare with that of saturated steam at 225 pounds pressure?

A. It will average 100 degrees higher.

Q. In what manner would you manipulate throttle and reverse lever, to get the best results in running an engine with superheater?

A. Run with throttle fully open, and reverse lever hooked back to short cut-off.

Q. At the same cut-off is more or less superheated steam necessary for the same amount of work as with ordinary steam? Explain.

A. Less, because superheated steam has a greater specific volume than saturated steam, and can be worked at a much shorter cut-off.

Q. With the same cut-off, why is the cylinder pressure higher at the end of the piston stroke with superheated steam than with saturated steam?

A. For the reason that there is much less cylinder condensation with superheated steam than there is with saturated steam. Consequently the pressure does not drop so quickly after cut-off occurs.

ELECTRIC HEADLIGHT

Q. Name the principal parts of the electric headlight.

A. The steam turbine, the dynamo, and the lamp.

STEAM HEAT

Q. What comprises the steam-heat equipment on a locomotive?

A. A throttle valve, steam heat gauge, relief valve, reducing valve, steam pipe and hose.

Q. What pressure is carried, and how controlled?

A. Twenty pounds for trains of five cars, and three pounds for each additional car. Forty-five pounds for heating up cold trains. By the reducing valve.

Q. How is steam admitted from boiler to steam-heat system?

A. Through steam pipe, reducing valve and connecting hose.

Q. Should the regulating valve ever be used as a stop valve?

A. It should not.

Q. Do you understand that the system is to be blown out rear end of train and steam shut off before engine is detached or train parted?

A. I do.

Q. Is it your duty to know that the steam-heat apparatus on the engine is operative before leaving the roundhouse track?

A. Is is.

Q. When engine is detached from the train, what precautions should you take to prevent freezing?

A. Allow sufficient steam to pass through to prevent steam pipe under tank from freezing.

AIR BRAKE QUESTIONS FOR THIRD-YEAR MECHANICAL EXAMINATIONS

Q. Name the principal parts of the automatic air brake on cars, and state the duties of each part.

A. The auxiliary reservoir, triple valve, train pipe,

brake cylinder and piston, pressure retaining valve, automatic slack adjuster.

AIR SIGNAL SYSTEM

Q. Name the parts of the air-signal apparatus on engines and cars, and state the duties of each part.

A. Signal pressure reducing valve to maintain the required pressure in signal pipe. Signal valve to admit air to signal whistle. Car discharge valve to permit proper reduction being made. Cut-out cocks and stop cocks.

AIR PUMPS

Q. Does the valve gear of the 11-inch and cross compound operate in practically the same manner?

A. It does; the cross compound valve motion being a serial arrangement of two simple compressors.

Q. What will cause the 9½-inch pump to blow on the up stroke? On the down stroke?

A. Loose rings on main piston, or either of the differential pistons; main slide valve, or reversing valve leaking.

Q. If pump stops below the maximum pressure, what should be done to get it started?

A. Reversing piston may be dry; steam blowing past the reversing valve rod; leak in reversing valve bush, or reversing cylinder; air strainer may be stopped up.

Q. What would cause the pump to stop at the bottom of the stroke, with a blow at the exhaust?

A. Shoulder on main valve may have worn into the slide valve.

Q. What will cause the pump to stop at the bottom of the stroke without a blow?

A. Reversing valve plate may be loose; ports in reversing valve bush may be stopped; packing rings on reversing or main valves may be bad.

Q. What will cause the pump to stop at the top of the stroke without a blow?

A. Reversing valve broken, or disengaged from reversing plate; loose reversing plate; bad packing rings on main valve piston or reversing piston.

Q. How can you tell if steam is reaching the pump properly?

A. Open drain cock in steam passage at pump.

Q. How would you test for leakage past air piston packing ring?

A. Notice whether the suction at air inlets is good for nearly the entire stroke. If it is not, the packing rings are leaking.

Q. Is a well-oiled swab necessary on pump piston rod?

A. It certainly is of great benefit.

Q. Should the pump be allowed to run over ash pit or while cleaning fires?

A. It should not.

Q. With a 9½-inch pump in good condition, what is its most efficient speed?

A. Not to exceed 120 single strokes per minute.

Q. What kind of oil should be used in air cylinder, what quantity, and where and how often applied?

A. Valve oil. Should be applied at frequent intervals, but never through the air inlets.

Q. Does a cross-compound pump require more lubrication than a simple pump?

A. It does.

Q. If necessary to remove the steam cylinder head, what should first be done?

A. Close all steam and air connections to the pump.

MAIN RESERVOIR

Q. Does the size of the main reservoir affect the operation of the brakes?

A. It does. It should be large enough to contain a sufficient volume of air to promptly charge up the train pipe and auxiliaries when empty.

Q. What harm will result if water is allowed to accumulate in the main reservoir?

A. It will pass into the train pipe and in winter will freeze and stop the pipe.

Q. How would you test for leakage from main reservoir and what is the effect of such leakage?

A. Air leaks necessitate working the air pump harder to keep up the pressure.

GOVERNORS

Q. If the governor stopped the pump below maximum pressure, and would not let it start, and you could not make repairs, what would you do? How?

A. Disconnect the upper from the lower section of the governor, remove the steam valve, and regulate the speed of pump by the air pump throttle.

Q. Why is the duplex governor provided, and what pressure does it control?

A. To control two different pressures, viz.: high speed service pressure, and low, or ordinary pressure.

Q. Where does the air come from that controls the minimum pressure head? The maximum pressure head?

A. Air passes to low-pressure head through the brake valve, and to high pressure head from main reservoir.

Q. Will similar causes of trouble produce similar effect in the different governors?

A. Yes; with this exception, that the older type of governor is controlled only by main reservoir pressure.

Q. Does the feed valve have any effect on the operation of the older type of governors?

A. Not the single pressure type, as they are controlled entirely by main reservoir pressure.

Q. Where does the air come from that is present on the under side of diaphragm of the excess governor head? In what position of the brake valve?

A. From main reservoir. With brake valve in either release, running or holding position.

Q. What is the standard main reservoir pressure on grades less than one and one-half per cent? On grades of one and one-half per cent and over?

A. Ninety pounds and 110 pounds.

Q. Where duplex governors are used, what should be the difference in adjustment of the two heads as regards pressure?

A. Twenty pounds.

Q. What is the allowable variation of the governor in controlling pump?

A. Theoretically there should be no variation.

GAUGES

Q. What is the purpose of the different air gauges used on the engine?

A. To properly indicate the air pressures in the different parts of the brake system.

Q. How can you test principal air gauge to prove probable correctness?

A. By means of a test gauge attached to train pipe-hose on tender. Place brake valve in full release for the red hand, and in running position for the black hand.

BRAKE VALVES

Q. What is the dividing line between main reservoir and brake-pipe pressure?

A. The rotary valve.

Q. Do you consider a leaky rotary dangerous?

A. I do.

Q. To what part of the brake valve is the equalizing reservoir connected, and for what purpose?

A. To chamber D for the purpose of enlarging it.

Q. What is indicated when the brake pipe gauge hand raises a few pounds after the brake valve is returned to lap, when applying brakes on a long train, and does not do it on a short train?

A. Train pipe overcharged.

Q. Describe in detail how a brake valve should be cleaned and lubricated.

A. Remove the cap nut from the rotary valve key, and fill with oil. Before replacing the cap nut push down on key, and rotate the handle a few times between release and emergency, then refill the oil hole, and replace the cap nut. The sides of the latch and notches on quadrant should also be lubricated.

FEED VALVES

Q. What is the purpose of the hand wheel and stops on the B-4 and B-6 feed valves?

A. For adjusting the valve for the pressure desired in the brake pipe.

E T EQUIPMENT

Q. To what part of the brake equipment is the distributing valve and its reservoir similar in operation?

A. The reducing valve.

Q. What change is there in the two lower pipes on the left-hand side as between number 5 and number 6 equipment?

A. On the No. 6 distributing valve the lower left hand pipe is the release pipe leading through the independent brake valve when the handle is in running position, and the other pipe just above it is the application cylinder pipe, leading to the independent, and automatic brake valves.

Q. Which is the most favorable to accomplish release on any train and avoid overcharging, a light application or a heavy one? Why?

A. This depends upon circumstances, and the particular type of brake in use. The first reduction should never be less than from 5 to 7 pounds, because less than this would not force the brake pistons over the leakage grooves in the cylinder.

Q. How does the E T distributing valve operate?

A. It permits air to flow from the main reservoirs to the brake cylinders when applying the brake; from the cylinders to the atmosphere when releasing the brake;

and automatically maintains the pressure against leakage, keeping it constant, when holding the brake applied.

Q. How will it affect the air pump if the strainer should become stopped up?

A. The pump will be slow about pumping up the pressure, as the strainer will not admit sufficient air to fill the cylinder at each stroke of the piston, causing it to work with a jerky motion.

Q. What would you do if the governor would allow you but 30 pounds of air in spite of all you could do to fix it?

A. Would cut out all air pressure from the governor, and endeavor to regulate the speed of the pump with its throttle.

Q. If short of air how can you distinguish quickly if the trouble is with pump or governor?

A. If after making an application, the speed of the pump does not increase under the reduced air pressure, there is something wrong with the governor. If the speed increases without increasing the pressure the trouble is with the pump.

Q. When could you use emergency?

A. Only in case of actual or probable danger. It should not be used when the engine is on the turn table.

Q. (a) When do wheels generally slide, at high or low speed? Why?

(b) Do you always notice your tank wheels before starting out, to see if any shoes are frozen to them in the winter.

A. (a) At low speed; because the pull of the brake shoe has exceeded the pull of the rail on the wheel.

(b) I do; and if I find any frozen I always thaw them out before starting.

Q. Which is the most liable to slide, a freight or passenger car? Why?

A. A freight car; owing to its lighter weight.

Q. How would you do braking on a passenger train on a slippery rail to prevent sliding wheels?

A. Would sand the rail before applying the brake, and would keep the rail sanded until the stop was completed.

Q. If it is impossible to depend on sand, as with a side wind, or sand pipes stopped up, how would you do braking?

A. Would apply the brakes in sufficient time to insure the safe holding of the train.

Q. With the same piston travel, will empty and loaded cars hold alike?

A. The loaded cars will hold better than empties.

Q. How should the brakes be applied on freight trains with different make up of train relative to loads and empties?

A. Would allow ample time for making the stop, and after shutting off would wait a little for the train to settle, and the slack to bunch if it will. Would then make the first reduction, which should in no case be less than 5 pounds, and again wait for the slack to come up. After the slack is bunched, would follow up as circumstances dictate, but never release until a full stop is made.

Q. On passenger trains at a high rate of speed where should a train be steadied by the brakes, on the curve, or approaching it?

A. The train should be steadied as it approaches the curve.

Q. (a) What harm is caused by leaving the 1889 engineer's valve on lap a long time, and then releasing it? Explain.

(b) Would you run a pump fast with the 1889 valve when on a grade?

A. (a) If the valve is placed on lap and allowed to remain there too long the pump is liable to run main reservoir pressure up too high, because the governor cannot shut the pump off, owing to the fact that with this type of valve, train pipe pressure operates the governor.

(b) I should run the pump very carefully.

Q. In testing brakes, why not use the emergency application?

A. Because the object in testing is to ascertain if all the brakes apply properly, and have the correct piston travel, and also that release takes place in the proper manner. The sudden heavy reduction of pressure in an emergency application would hardly be a fair test.

Q. How do you handle the different engine equipments to prevent heating of the tires on a grade?

A. If the drivers slide would place the independent brake valve handle in release position and hold it there until the wheels again revolve; then if desired, would reapply the brakes with this brake valve.

Q. Does a poor driver and tender brake have a tendency to increase the flat wheel record on cars? How?

A. Yes; owing to the fact that the principal portion of the braking must in such cases be done on the train, and reductions may at times be too heavy.

Q. (a) If, when making a stop with a heavy freight train, the drivers should begin to slide, and you

did not dare to release the brake for fear of breaking in two, what would you do?

(b) What would you do if equipped with combined automatic and straight air brake?

(c) With E T equipment?

A. (a) Would release all brakes and sand the rail, then apply driver brakes and immeditely afterward train brakes.

(b) Should re-apply driver brakes with straight air.

(c) Would try to graduate driver brakes off enough to permit the wheels to revolve; then sand the rail and graduate on again.

Q. When should hand brakes be used at rear end of train?

A. When backing a freight train out of a side track, if the train is only partially equipped with air brakes.

Q. How many air brake cars should be operated by one engine?

A. That depends upon the size of the air pump. The number of auxiliary reservoirs should not be beyond the capacity of the air pump to keep them charged.

Good Luck!

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